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THIS VOLUME 2 OF A TWO-VOLUME SET PROVIDES AUTOINSTRUCTION IN PHYSICS. THE UNITS COVERED IN THIS VOLUME ARE (1) REFLECTION OF LIGHT, (2) PHOTOMETRY, (3) POLARIZATION, (4) REFRACTION OF LIGHT, (5) SNELL'S LAW, (6) LENSES, FOCUS, AND FOCAL POINTS, (7) IMAGE FORMATION, AND (8) ABERRATIONS, THE EYE, AND MAGNIFICATION. THE INTRODUCTION AND UNITS ON STATIC ELECTRICITY ARE CONTAINED IN VOLUME 1, ED 003 657. (RS)

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(2)

VOLUME 2

REFLECTION AND REFRACTION

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Pittsburgh, Pennsylvania

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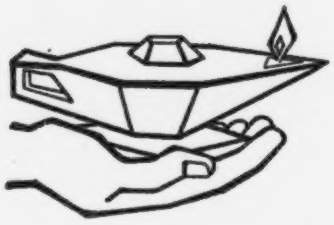
These materials were prepared for use in an experimental study of the self-tutoring approach in education. Further information concerning the design of the study and the data obtained are contained in reports available from the American Institute for Research.



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DIRECTIONS FOR USING THIS BOOK

The pages of this book have been arranged in a special way. Here is how to follow along and do the steps in the right order.

As you start each unit, the steps will be along the top row of the pages. You should read step 1, write your answer, and then turn the page to see the correct answer on the following page. The answer to step 1 will also be at the top on the right-hand page. To see step 2, you should again turn the page, always looking at the top of the next right-hand page. You always have to turn to the next page to find the answer to a question, and then turn the page again to go on to the next question.

Each unit begins and ends with a yellow page. When you get to the last page of the unit, you will see directions telling you how to turn the book around and go on with the next step.

Altogether, there are five rows of steps on each page. You should only pay attention to the steps in the row you are working on.

Once you get started, you will find it is easy to follow along properly. Just be sure you do the steps in their proper order. Each step has been numbered to help you. The question for each step is numbered with a capital letter (like A-27) and the answer for that step is numbered with a small letter (like a-27).

Remember, after answering each question, turn the page to see the answer, and then turn the page again to see the next step.

Do not try to do too much at one time. You will make fewer errors and remember more of what you have learned if you stop and relax every once in a while.

③
X

UNIT ONE

LIGHT SOURCES
AND THE
RECTILINEAR PROPAGATION
OF LIGHT

Steps C-1 through C-120

④
X

BEGIN UNIT HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

UNIT ENDS HERE

C-1

In physics, the study of the way light rays act is called optics. In studying optics, you must learn how light originates. The study of the way light acts as it moves from place to place and how light originates is called ______.

C-25

All substances will emit light; that is, become ______, if they are heated sufficiently. In addition to tungsten, we often use carbon to produce light, either in a carbon filament lamp or a carbon arc lamp. Some substances, such as the gas in a ______ sign will emit light without being heated. These are not ______ sources of light.

C-49

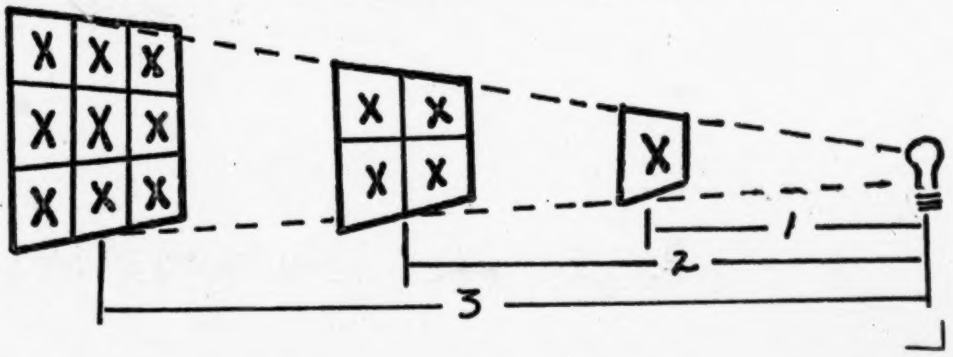
Illuminance is measured in units called lumens. As the candlepower of the source is increased, the number of ______ produced by the source is increased.

C-73

To show how a shadow is formed, we need to use an opaque (say, oh-pake) material. An opaque material is one which does not let light pass through it. We can see through transparent materials but we cannot see through ______ materials.

C-97

The figure shows how illumination decreases as the distance to the light source increases. The light which illuminates a one square foot of surface at a distance of one foot must illuminate four square feet at a distance of #______ feet and #______ square feet at a distance of #______ feet.



A·I·R ©1960

c-120

illumination

---

c-96

increases

---

c-72

rectilinear propagation

---

c-48

amount of light (or, light flux) that flows from a light source in a given direction

---

c-24

electric current
mercury

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⑦

c-1

optics

c-25

incandescent
neon (or, mercury vapor)
incandescent

c-49

lumens

c-73

opaque

c-97

2
9
3

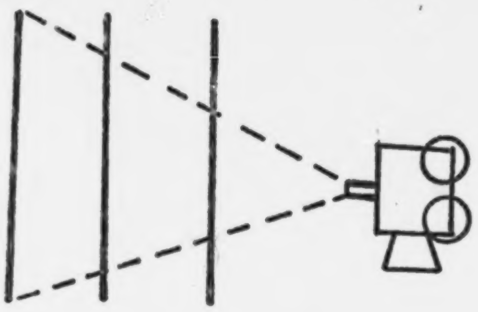
A·I·R ©1960

C-120

An illuminometer measures the ______; that is, the amount of light, falling on the surface of its photoelectric cell.

C-96

As the screen is moved farther from a movie projector, the image on the screen becomes larger but the illumination at any point becomes less. This shows that the illumination of a given area of surface decreases as the distance to the light source ______.



C-72

One part of geometrical optics is the study of shadows. The way shadows are formed is evidence for the straight-line travel, or * ______ of light.

C-48

Illuminance is the ** ______.

C-24

Fluorescent substances, such as the powdery coating inside a fluorescent tube or bulb, emit visible light when they are exposed to ultraviolet light. In a fluorescent lamp, the ultraviolet light is produced by passing an * ______ through ______ vapor.

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⑨

C-2

In beginning your study of light, or ☐, you have to know how light is originated. A very important source of light is the sun.

C-26

A tungsten filament lamp or a carbon arc lamp produce light because they are heated until they become ☐. Neon gas and mercury vapor emit light, not because they are heated, but because we pass an ☐ * through them.

C-50

The luminous intensity of a light source is measured in units based on the amount of light emitted by a standard candle. This unit is called a ☐. Illuminance, the amount of light flowing away from a source in a given direction, is measured in units called ☐.

C-74

Clear glass, air and water are examples of transparent materials. Wood, steel and brick are examples of ☐ materials. Light will not pass through ☐ materials.

C-98

Mathematically, as the distance to the light source increases, the amount of illumination ☐ proportionally to the square of the distance. If the distance between the source and the screen is doubled (multiplied by 2) the illumination on a given area is only one-fourth of what it formerly was.

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c-119

illuminometer
photoelectric cell

c-95

increases
less

c-71

point
extended

c-47

illuminance
luminous intensity

c-23

heating

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⑪

c-2

optics

c-26

incandescent

electric current

c-50

candlepower

lumens

c-74

opaque

opaque

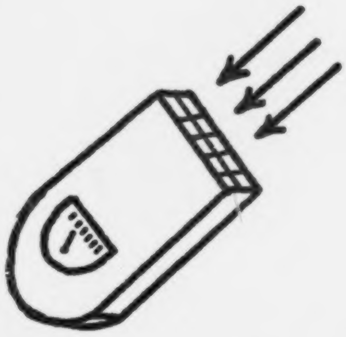
c-98

decreases

A·I·R ©1960

C-119

An illuminometer contains a "photoelectric cell" which is a special material, such as selenium, that converts radiant energy into a small electric current which, in turn, operates the meter (or pointer). The figure illustrates an ______. Light which strikes the top of the device activates a * ______ inside of it.



C-95

The illumination of a given area of a surface decreases as the distance to the light source ______. If we place a movie screen near the projector, and then move it farther away, we would see that the image on the screen would become larger, but that the illumination of a given screen area was (greater/less) ______ than before.

C-71

In studying geometrical optics, we use a small or ______ source of light rather than a large or ______ source of light.

C-47

The amount of light which flows through space in a given direction from a light source is called the ______. The amount of light which is emitted by a source of light depends on its * ______; that is, how powerful a source of light it is.

C-23

The ultraviolet light produced by passing an electric current through the mercury vapor causes the coating in the tube of a fluorescent lamp to emit visible light. The light emitted by the coating of a fluorescent lamp is not incandescent because it was not produced by ______ the coating.

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C-3

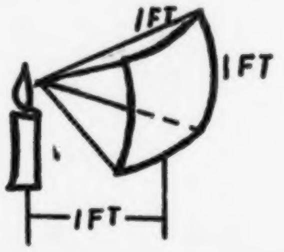
The sun is a very important ______ of light. Light bulbs are other important *______.

C-27

We say the sun and stars are luminous bodies because they emit light. Any object which emits light, whether it is incandescent or not, is said to be ______.

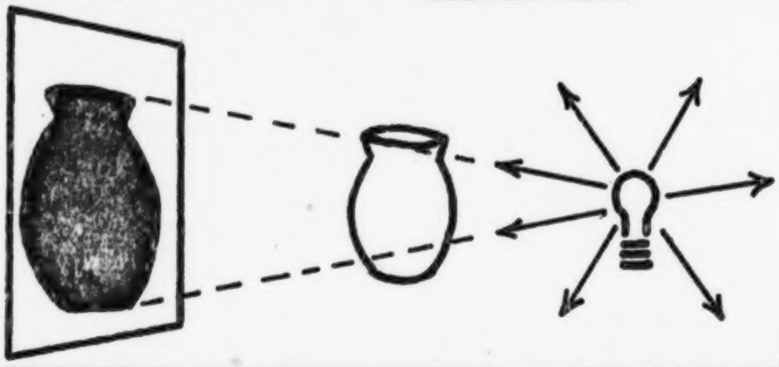
C-51

A lumen is defined as the amount of light that would flow through an opening, one foot square, which was one foot away from a one candlepower source of light. A lumen is the unit used to measure ______.



C-75

We can see a shadow when an opaque object is placed between a light ______ and the surface, such as a screen or wall, we are looking at. The ______ object will prevent some of the light from striking the surface.



C-99

That the illumination of a surface increases as the luminous intensity increases and decreases as the square of the distance to the source, is known as the inverse square law. To find the illumination on a surface, we divide the luminous ______ of the source by the ______ of the distance to the source.

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c-118

illuminometer
exposure

c-94

B

c-70

point source
extended

c-46

illuminance
illuminance

c-22

emit light (or, give off light)
radiant

A·I·R ©1960

⑮

c-3

source
sources of light

c-27

luminous

c-51

illuminance

c-75

source
opaque

c-99

intensity
square

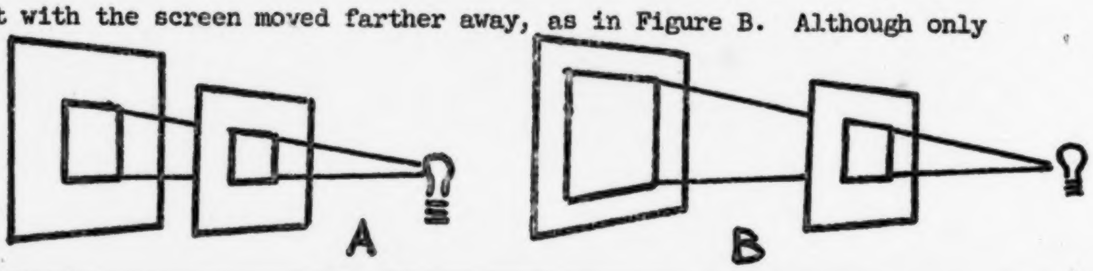
A·I·R ©1960

C-118

An instrument for measuring illumination is called an ______. Engineers use one type, a foot-candle meter to measure illumination in foot-candles. Photographers use another kind, an ______ meter to guide them as they set their camera.

C-94

Suppose we projected 1 lumen of light through a small square hole on to a screen, as in Figure A, and then tried it with the screen moved farther away, as in Figure B. Although only 1 lumen is passing through the hole in each case, the area of surface it must illuminate is greater in figure $ ______.



C-70

A small source of light is known as a * ______ of light. The opposite of this is an extended source of light. A large object serving as a source of light is known as an ______ source of light.

C-46

As the luminous intensity of a light source is increased, it gives off a greater amount of light in all directions. The amount of light that flows in a given direction can be measured. We call this the ______. As the luminous intensity of a source is increased, the ______ is also increased.

C-22

When mercury is heated, it vaporizes. Like neon, when we pass an electric current through it, it will * ______. The vapor produces some visible blue light. It also produces some "ultraviolet" light which is not visible. Both the blue light and the ultraviolet light are forms of ______ energy.

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C-4

Light is one form of radiant energy. All sources of light, such as the sun, electric [*], and fires, emit or give off [*].

C-28

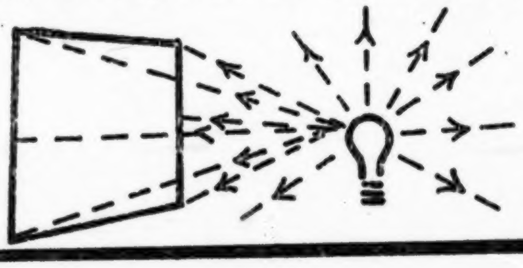
The sun is a natural luminous object. An electric light bulb is an artificial source of light; but it is also a [ ] object.

C-52

The amount of light that would flow through an opening one foot square, which was one foot away from a one [ ] source of light is called one [ ].

C-76

A source of light emits some light in all [ ]. When we see a shadow, we are only concerned with the light that travels toward that surface, however. In the figure, not all the light which is being emitted by the source [*]. Since the source is a small one, we describe it as a [*].



C-100

The inverse square law states that the [ ] of a surface is proportional to (increases as we increase) the [*] of the source and is inversely proportional to (decreases as we increase) the square of the [ ] between the surface and the light source.

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c-117

illuminometers

c-93

greater

more

c-69

point

c-45

illuminance

c-21

incandescent

A·I·R ©1960

⑲

c-4

light bulb
radiant energy (or, light)

---

c-28

luminous

---

c-52

candlepower
lumen

---

c-76

directions
strikes the surface
point source of light (or, light source)

---

c-100

illumination
luminous intensity
distance

A·I·R ©1960

C-117

Foot-candles can be measured with an instrument called an illuminometer (say, ill-loom-in-om-iter). If the scale on the meter is in foot-candles, it is called a foot-candle meter; if the scale indicates camera settings, it is called an exposure meter. Both foot-candle meters and photographic exposure meters are forms of ________.

C-93

The closer to a light source the surface is, the (greater/less) ________ is the illumination on that surface. A surface 2 feet from a light source would be (more/less) ________ brightly illuminated than an equally sized surface 10 feet away.

C-69

When we study geometrical optics, we use a "point" source of light; that is, a very small source of light. In showing how a shadow is formed, for instance, we show light coming from a small source, a ________ source of light.

C-45

Illuminance is a second way of measuring the light being produced by a source. Illuminance is the flow of light, or "light flux" that is traveling in a given direction away from a light source. The amount of light flowing through a window is the ________ passing through the window.

C-21

The "luminous" dial on a watch does not have to be heated to emit light; it is not an ________ source of light.

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㉑

C-5

That part of ______ energy we can see is called light. Light, as well as heat and radio waves, are all forms of * ______.

C-29

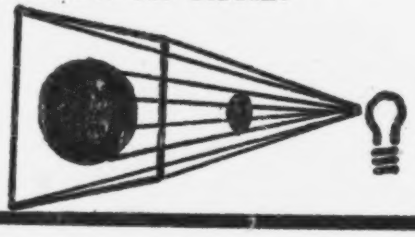
The sun and a flashlight bulb are both luminous objects, but one gives off more light than the other. This is because one has a greater luminous intensity than the other. The luminous ______ of the sun is, of course, much greater than the * ______ of a flashlight bulb.

C-53

Engineers who design lighting fixtures prefer to use lumens rather than candlepower as their unit of measure. A lumen is the unit used to measure the amount of light flowing away from a source in a given direction, while a candlepower is used to measure the ** ______.

C-77

A shadow is formed when an opaque object is placed between a light source and a screen. Because of the straight line travel or * ______ of light, any of the light that strikes the object (will/will not) ______ illuminate the screen.



C-101

In symbols, I stands for luminous intensity of the source, r for distance, and E for illumination. In symbols, then, $E = \frac{I}{r^2}$ is the * ______ law.

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c-116

5

---

c-92

closer to

---

c-68

straight line

---

c-44

emitted

---

c-20

electric current
incandescent

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㉓

c-5

radiant
radiant energy

c-29

intensity
luminous intensity

c-53

(luminous) intensity of the light source

c-77

rectilinear propagation
will not

c-101

inverse square

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C-116

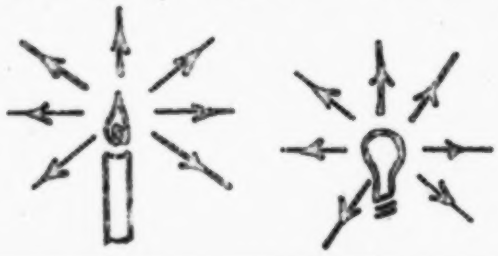
A 100 watt light bulb has a luminous intensity of 125 candlepower. It will illuminate a surface with 5 foot-candles if the surface were # ______ feet away.

C-92

The illumination or amount of light falling on a surface also depends on the distance from the light source to the surface. If we are trying to read with the light of a small light, we can increase the illumination on the page by moving (closer to/farther from) ______ the light source.

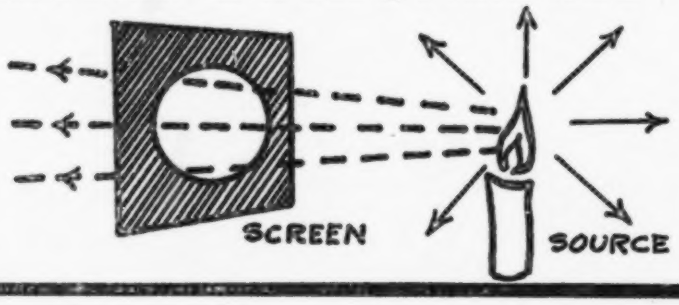
C-68

Some light is emitted in all directions from a light source, as shown in the figure. No matter which direction it travels, however, the path along which a ray of light travels is a * ______ ______.



C-44

Light flows outward in all directions from a source. If we hold up a screen with a hole in it near a source of light, some of the light being ______ by the source will flow through the hole. This is the amount of illuminance at that point.



C-20

Some sources of light are not incandescent. Neon and mercury vapor, for instance, do not emit light because they are heated, but because we pass an * ______ through them. If a source of light does not depend on being heated to produce light, it is not an ______ source of light.

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C-6

The sun is a natural source of light. An electric light bulb, however, is an artificial [*]. Both of these sources emit light, which is a visible form of [*].

C-30

Very dim sources of light, such as a kerosene lantern, have low [*]. Bright sources of light, such as a giant searchlight, have high [*].

C-54

One candlepower of light source produces 12.57 lumens of light flux. A 10 candlepower source would produce [#] lumens of light.

C-78

If a nontransparent, or [ ] object is placed near the screen (Figure 1), it will cast a small shadow, but if it is placed near the light source (Figure 2), [**].

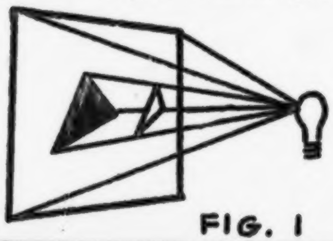

FIG. 1

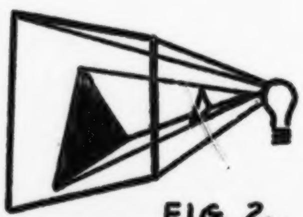

FIG. 2

C-102

In the formula for the [*] law, $E = \frac{I}{r^2}$, E, or [ ] is measured in units called foot-candles, I in candlepower, and r in feet. In units of measure, the law would be expressed as foot-candles = $\frac{[\ \ ]}{[*]}$.

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c-115

13.75

c-91

greater

c-67

straight line

c-43

luminous intensity of a source

c-19

electric

A·I·R ©1960

27

c-6

source of light
radiant energy

c-30

luminous intensities
luminous intensities

c-54.

125.7

c-78

opaque
it will cast a large shadow

c-102

inverse square
illumination

$\frac{\text{candlepower}}{\text{feet squared}}$

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C-115

An ordinary 50 watt light bulb has a luminous intensity of about 55 candlepower. A surface 2 feet away would be illuminated to # ______ foot-candles.

C-91

The greater the luminous intensity of a light source, the (greater/less) ______ will be the illumination of a surface in the path of the light.

C-67

In studying geometrical optics, we are concerned with the rectilinear propagation or the fact that light travels in a * ______.

C-43

Candlepower is the unit used to measure the ** ______. The amount of light emitted by a source depends on its luminious intensity.

C-19

A fluorescent lamp is another artificial source of light. It contains tiny filaments which heat a small amount of liquid mercury until it becomes a vapor or gas. This gas, like neon, will emit light when we pass an ______ current through it.

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C-7

Heat, radio waves, and light are all forms of [*]. The sun emits, or [*] many forms of radiant energy. The heat and light it emits are necessary to life on earth. An electric light bulb also gives off, or [ ] more than one form of radiant energy. It gives off both heat and [ ].

C-31

A luminous body is an object which [*].

C-55

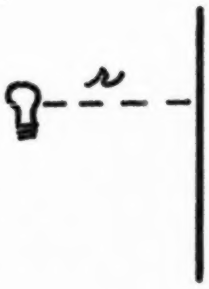
Since one candlepower equals 12.57 lumens, we can find the candlepower of a light source which is producing a total illuminance of 75.42 lumens by dividing 75.42 by [#]. This source has a luminous intensity of [#] candlepower.

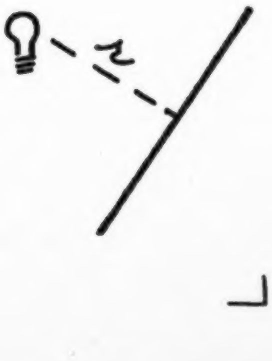
C-79

An extended, or [ ] source of light will produce fuzzy shadows, but a small, or [ ] source of light will produce a shadow with sharp, clear edges. We only get shadows with sharp edges when we use a [*] of light.

C-103

Finish the formula for the inverse square law, E = [$]. To use this formula, we measure distance perpendicular to the surface. (See figures.)





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c-114

small
extended

c-90

increase
luminous intensity
increases

c-66

rectilinear propagation

c-42

candlepower
60

c-18

filament
emit light (or, give off light)

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(31)

c-7

radiant energy
gives off
emits
light

c-31

emits (or, gives off) light

c-55

12.57
6

c-79

large
point
point (or, small) source

c-103

$(E =) \frac{I}{r^2}$

C-114

The inverse square law applies only to point sources of light; that is, ______ sources of light. If the source is large; that is, if it is an ______ source, the law does not apply unless the distance from the source to the surface is very great.

C-90

If you replace a 40 watt bulb in a desk lamp with a 100 watt bulb, the illumination of the desk surface will (increase/decrease) ______. Illumination increases as the * ______ of the light source (increases/decreases) ______.

C-66

When we study phenomena such as shadows, we are studying geometrical optics. Geometrical optics deal with the straight-line travel, or the * ______ ______ of light.

C-42

Luminous intensity indicates how powerful a source of light any luminous object is, regardless of which direction the light is going. Luminous intensity is measured in units called ______. One square centimeter of molten platinum has a luminous intensity of # ______ candlepower.

C-18

Aside from the incandescent sources of light such as the tungsten ______ lamp we have been describing, there are other artificial sources of light. One of these is the neon tube used in a neon sign. When we pass an electric current through the tube, the neon gas inside the glass tube will * ______.

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C-8

The moon reflects the light from the sun. It does not emit light of its own. The sun is a ☐ of light, but the moon is not a [*]. The light we see coming from the moon and the planets is reflected sunlight.

C-32

An object which emits very little light has a low ☐ intensity. An object which emits a great deal of light has a high [*].

C-56

Since one candlepower equals 12.57 lumens, a light bulb producing a total illuminance of 50.28 lumens has a light intensity equal to [#] candlepower.

C-80

If the source of light is small, any shadow it produces will generally be (sharp/fuzzy) ☐. If the source is an extended source, the shadows produced by it will be (sharp/fuzzy) ☐.

C-104

Foot-candles are the unit used to measure the ☐ of a surface. In units of measurement, the inverse square law is stated as foot-candles =

[*].

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c-113

illumination on a surface is proportional to (is increased as you increase) the luminous intensity of the source, and is inversely proportional to (is decreased as you increase) the square of the distance to the source.

c-89

illumination

c-65

rectilinear propagation

c-41

luminous intensity (or, candlepower)

c-17

emit light
incandescent

A·I·R ©1960

(35)

c-8

source

(natural) source of light

c-32

luminous

luminous intensity

c-56

4.0

c-80

sharp

fuzzy

c-104

illumination

$\frac{\text{candlepower}}{\text{feet squared}}$

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C-113

In words, the inverse square law states that ** ____ .

C-89

The amount of light falling on a surface; that is, the ________ of a surface depends on the luminous intensity of the light source and the distance between the light source and the surface.

C-65

The fact that light travels in straight lines is known as the rectilinear propagation (say, rek-ti-lyn-ee-ar prop-a-gay-shun) of light. The way shadows are formed has to do with the straight-line travel or * ________ of light.

C-41

The headlights of an automobile several miles away do not appear to be as bright as those of an automobile next to us. Nevertheless, the amount of light being emitted by each source is the same, so we know that the * ________ of each source must be the same.

C-17

When we pass an electric current through an electric light bulb filament, it heats up and becomes incandescent, which means it will * ________ . Although we almost always use tungsten as a filament in light bulbs, any material when heated sufficiently, will become ________ ; that is, emit light.

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C-9

The stars we see all emit light. We can also see the moon and planets, but they do not ________ light. The moon and the planets reflect light which was emitted by the ________.

C-33

The luminous intensity of an object is measured in units called "candlepower." An object which emits 50 candlepower gives off (more/less) ________ light than one which emits 10 candlepower.

C-57

To convert candlepower to lumens, we use the formula, 1 candlepower = # ________ lumens.

C-81

It is also possible to demonstrate the straight line travel or * ________ of light by using a small screen with a pin-hole in it. Aside from the pin-hole, the screen must not let any light through it; that is, it must be ________.

C-105

In symbols, the formula for finding the illumination of a surface is $ ________.

If we placed a 20 candlepower source 2 feet away (in a perpendicular line) from a surface, the surface would have an illumination of # ________ foot-candles.

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c-112

inverse square law
increase
decrease

c-88

illumination

c-64

straight line

c-40

greater
greater
more

c-16

tungsten filament lamp
filament

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39

c-9

emit

sun

c-33

more

c-57

12.57

c-81

rectilinear propagation

opaque

c-105

$E = \frac{I}{r^2}$

$(\frac{20}{2^2} = \frac{20}{4} =)$ 5

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C-112

$E = \frac{I}{r^2}$, which is the formula for the ☐ * , states that, to increase illumination, we could (increase/decrease) ☐ the luminous intensity of the source or (increase/decrease) ☐ the distance from the source to the surface.

C-88

The illumination of a surface refers to the amount of light falling on it. For example, a 150 watt light bulb furnishes more ☐ on the surface of a desk than a 75 watt bulb.

C-64

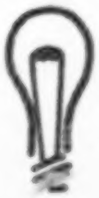
One important property of light is that it travels in straight lines. No matter what kind of source we use, the light will travel in a ☐ * .

C-40

The luminous intensity of a giant searchlight is (greater/less) ☐ than that of the light bulb in a desk lamp. A bonfire has (greater/less) ☐ luminous intensity than a candle. A source of high luminous intensity is a more powerful source of light than one of low luminous intensity. It will therefore emit (more/less) ☐ light than a source of low luminous intensity.

C-16

The figure is an illustration of the kind of light bulb known as a ☐ * . The fine coil or spiral of wire inside it is called a ☐.



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C-10

Most sources of light are "incandescent"; that is, they give off light because they are hot. The sun, a fire, and an electric light bulb are sources of ______ light.

C-34

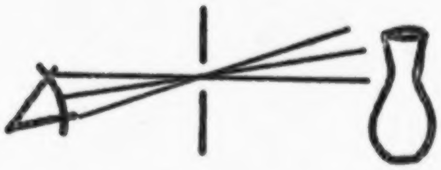
One candlepower of light is the intensity of a specially made "standard candle." A 60 candlepower source of light would emit # ______ times as much light as one of these specially made * ______.

C-58

Candlepower is the unit of * ______. Lumen is the unit of ______.

C-82

Suppose we looked through a pin-hole toward a vase. If our eye were slightly below the hole, as in the figure, all we could see would be the (top/bottom) ______ part of the vase.



C-106

If we placed a 100 candlepower source 5 feet from a surface, the surface would have an illumination of # ______ foot-candles.

A·I·R ©1960

c-111

(20 = $\frac{X}{3^2} = \frac{X}{9}$, 9 times 20 = X =) 180

---

c-87

luminous intensity
illuminance

---

c-63

luminous intensity
candlepower
illuminance
lumens
illumination

---

c-39

intensity
60

---

c-15

incandescent
light

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c-10

incandescent

c-34

60

standard candles

c-58

luminous intensity

illuminance

c-82

top

c-106

$\left(\frac{100}{5^2} = \frac{100}{25} =\right)$ 4

A·I·R ©1960

C-111

If a surface has an illumination of 20 foot-candles and is 3 feet from a source, the source has a luminous intensity of [#] candlepower.

C-87

Earlier, you learned about luminous intensity, which describes how powerful a source of light is, and illuminance, which was the amount of light or flux flowing away from a source in a given direction. Candlepower is the unit of [*] and lumen is the unit of [ ].

C-63

If we observe sunlight coming through a window and falling on a table, we can describe the [*] of the source in units of [ ]; the amount of light flowing through the window, or [ ], in units called [ ]; and the amount of light falling on the surface; that is, the [ ] of the surface.

C-39

One square centimeter of molten platinum has a luminous [ ] equal to [#] candlepower.

C-15

The light source in a tungsten filament lamp is a coil of fine tungsten wire suspended on two or three posts. The fine spiraled wire is called a filament. If an electric current flows through the filament it will heat up, or become [ ], and emit [ ].

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C-11

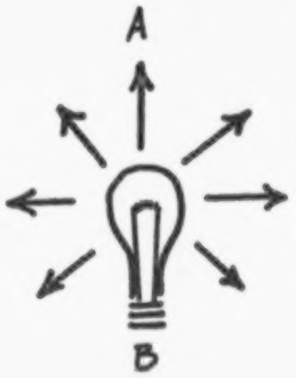
Not all sources of light are incandescent. The hands of a watch that shine in the dark, or a firefly's light, do not depend upon heat. They are not examples of ☐ light.

C-35

The luminous intensity of a light source can be measured by comparing it with the luminous intensity of a standard candle. A 40 candlepower source emits ☐ # times as much light as one standard candle. A source which emits 15 times as much light as one standard candle has a luminous intensity of 15 ☐.

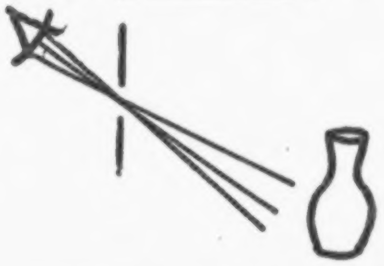
C-59

Illumination engineers prefer to measure light in lumens because light sources do not emit an equal amount of light in all directions. A light bulb, for instance, emits more light away from its base than it does toward its base; that is, the illuminance toward ☐ $ is greater than toward ☐ $.



C-83

If we moved our eye to above the hole, we would only see the ☐ part of the vase.



C-107

To find the correct distance to place a 640 candlepower source in order to produce 40 foot-candles of illumination on a surface, we use the formula $E = \frac{I}{r^2}$. Substituting, we get $40 = \frac{640}{r^2}$. Using algebra, we can multiply both sides by r^2, or $40\ r^2 = 640$. Then, divide both sides by 40, or $r^2 = \frac{640}{40} = \frac{64}{4} = 16$. Since $r^2 = 16$, r = ☐ # feet.

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c-110

(8 =) $\frac{I}{r^2}$

(8 = $\frac{X}{5^2}$ = $\frac{X}{25}$, 8 times 25 = X, or X =) 200

---

c-86

shadow
inverted

---

c-62

luminous intensity
illuminance
illumination

---

c-38

standard candles

---

c-14

tungsten filament lamp

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(47)

c-11

incandescent

c-35

40
candlepower

c-59

A
B

c-83

bottom

c-107

4

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C-110

We can also use the formula E = $ to find the candlepower of a source if we know its distance from a surface and the amount of illumination on that surface. For instance, if a surface illumination is 8 foot-candles, a source of light 5 feet away must have a luminous intensity of about # candlepower.

C-86

The rectilinear propagation of light can be demonstrated by the fact that an opaque object placed between a light source and the surface we are looking at will cast a ☐. It can also be demonstrated by the fact that a picture projected through a pin-hole will be upside down, or ☐.

C-62

The amount of light emitted by a source depends on how powerful a source of light it is; that is, its * . The amount of light, or light flux, flowing in a given direction is called ☐. The amount of light falling on a surface is called ☐.

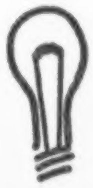
C-38

Because all standard candles did not emit exactly the same amount of light, the U. S. Bureau of Standards developed a different standard: the amount of light emitted by one square centimeter of molten platinum. This, they said, had a luminous intensity of 60 candlepower, which means it emitted an amount of light equal to that produced by sixty _*

_

C-14

Most "light bulbs" are tungsten filament lamps. Tungsten is a kind of metal. The figure illustrates the kind of light bulb known as a * .



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C-12

An incandescent source of light is one which ** ____________ ____________.

C-36

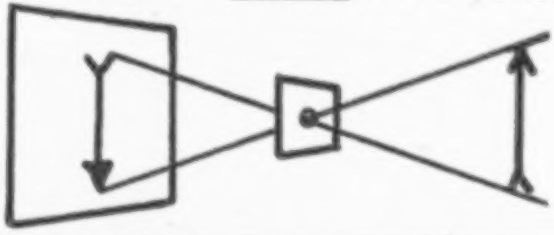
A unit called a ____________ is used to measure the * ____________ of a light source. The more powerful the source of light, the more candlepower of intensity it has and, therefore, the more light it will emit.

C-60

Luminous intensity is how powerful a source of light some luminous object is. Illuminance is the amount of light flux flowing away from a luminous object in a given direction. Illumination, on the other hand, is the amount of light which falls on a surface. If we increase the amount of light which falls on the surface of an object, we have increased the ____________ on that object.

C-84

If we had a light source shaped like an arrow, and projected the light from this source through a pin-hole and onto a screen, we would see that the arrow was inverted, or turned upside down. This also demonstrates the straight-line travel, or * ____________ of light.



C-108

To use the formula $E = \frac{I}{r^2}$ to find distance when illumination and luminous intensity are known, first insert the known values in the formula. If E = 3 and I = 108, we would have

$\boxed{\#} = \frac{108}{r^2}$. Then, $r^2 = \frac{108}{3}$ or $r^2 = \boxed{\#}$, and $r = \boxed{\#}$ feet.

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c-109

$(20 = \frac{720}{\text{feet}^2}$, $\text{feet}^2 = 36$, or) 6 (feet)

c-85

inverted

c-61

illumination

c-37

candlepower

candle

c-13

source of light

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(51)

c-12

emits (gives off) light because it is hot

c-36

candlepower
luminous intensity

c-60

illumination

c-84

rectilinear propagation

c-108

3
36
6 (feet)

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C-109

For reading, there should be close to 20 foot-candles of illumination on the page. If you had a 720 candlepower source of light, it should be placed about [#   ] feet from the surface of the page.

C-85

When something is inverted, it means it is turned upside down. If the picture of something is projected through a pin-hole onto a screen, the picture on the screen will be upside down, or [   ].

C-61

The amount of light which falls on a surface is called [   ].

C-37

The luminous intensity of an object is measured in terms of a unit called a [   ]. This represents the amount of light given off by one specially made standard [   ].

C-13

The most familiar artificial source of light is a light bulb. While the sun or a candle is a natural source of light, an electric light bulb is an artificial [*   ].

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TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

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X

UNIT TWO

PHOTOMETRY AND THE VELOCITY OF LIGHT

Steps C-121 through C-247

BEGIN UNIT HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

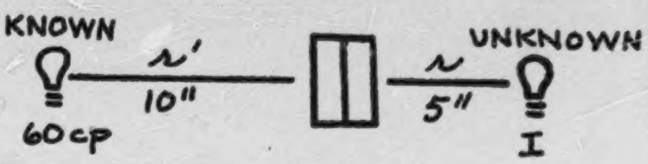
UNIT ENDS HERE

C-121

Photometry (say, foh-tom-eh-treé) is the measurement of the intensity of a source of light. In order to find the luminous intensity of a light source we use a technique called ______.

C-147

If I', the luminous intensity of a standard source, is known to be 60 cp (candlepower); and, when E = E', r is 10 inches and r' is 5 inches, then the value of I can be found. Since $\frac{I}{r^2} = \frac{I'}{r'^2}$, we can write $\frac{I}{10^2} = \frac{60}{5^2}$, or $\frac{I}{100} = \frac{60}{25}$, or $I = \frac{6000}{25}$, or I = #______ cp.



C-173

Light has a velocity of about #______ kilometers per second; that is, about #______ miles per second.

C-199

In symbols $\mu = \frac{c}{v}$. In words, this formula reads **______.

C-225

A point source of light is a ______ source of light. An extended source of light is a ______ source of light.

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c-224

travels in straight lines
rectilinear propagation (or, straight-line travel)

c-198

index of refraction
velocity of light in a vacuum
velocity of light in another medium

c-172

300,000
186,000

c-146

I'
r^2
r'^2

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59

c-121

photometry

c-147

240

c-173

300,000
186,000

c-199

index of refraction equals velocity (of light) in a vacuum divided by the velocity (of light) in another medium.

c-225

small
large

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C-224

When we say light has rectilinear propagation, we mean that light * ______ . The way shadows are formed is evidence for the * ______ of light.

C-198

The Greek letter μ (say, mew) is used to abbreviate index of refraction, c stands for the velocity of light in a vacuum, and v is used to indicate the velocity of light in another medium. In symbols, then, μ or the * ______ , equals c, or the * ______ divided by v, or the * ______ .

C-172

Many other people have also measured the speed of light. They have found that, in a vacuum, light has a velocity of about 300,000 kilometers per second, or about 186,000 miles per second. Another way of saying this is that in one second, light will travel # ______ kilometers or # ______ miles.

C-146

Since $\frac{I}{r^2} = \frac{I'}{r'^2}$ when E = E', we can find the candlepower of the unknown source, or I, by knowing the candlepower of the known source or $ ______ , the distance to the unknown source squared, or $ ______ , and the distance to the known source squared, or $ ______ .

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C-122

To determine the candlepower of a light source, we use a measuring technique called ______; that is, we measure the * ______ of the source. We do this by comparing the intensity of the source with the intensity of another source of known candlepower.

C-148

Solve for I when I' = 40 cp, r = 6, and r' = 4. Since $\frac{I}{r^2} = \frac{I'}{r'^2}$, $\frac{I}{36} = \frac{40}{16}$, $I = \frac{1440}{16}$

I = # ______ cp.

C-174

Very soon after Fizeau measured the speed of light, another Frenchman named Foucault (say, Foo-koh) also measured its speed using a different apparatus. Using a rotating mirror, he also found that light had a velocity of about # ______ kilometers per second, or # ______ miles per second.

C-200

Write the formula for index of refraction using symbols, $ ______.

C-226

Shadows have sharp edges if the opaque object causing the shadow is between a surface and a small or ______ source of light. If an ______ object is between a surface and a large or ______ source of light, the shadow will be fuzzy.

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c-223

falls on a surface

c-197

refraction

c-171

measured

c-145

unknown candlepower (luminous intensity)

$\frac{I'}{r'^2}$ (and) $\frac{I}{r^2}$

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c-122

photometry
luminous intensity

c-148

90

c-174

300,000
186,000

c-200

$\mu = \frac{c}{v}$

c-226

point
opaque
extended

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C-223

Illumination is the amount of light which * ______. Illumination is measured in units called foot-candles.

C-197

The ratio, $\frac{\text{velocity of light in a vacuum}}{\text{velocity of light in another medium}}$, is known as the index of ______.

C-171

By knowing how much time it took for the wheel to rotate enough for a tooth to move into the path of the returning light, and the distance to the mirror on the hilltop and back, Fizeau was able to calculate the speed of light. He found that although the velocity of light was very fast, it was finite; that is, it could be ______.

C-145

We know that for the side of known candlepower, $E' = \frac{I'}{r'^2}$, and that for the side of * ______, $E = \frac{I}{r^2}$. When we adjust the photometer so that $E' = E$, we know that the proportions $ ______ and $ ______ must be equal to each other since they are each equal to E' and E.

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C-123

The technique of measuring the * ______ of an unknown source by comparing the light it emits with the light emitted by a known source is called ______.

C-149

Solve for I when I' = 20 cp, r = 4 inches, and r' = 8 inches; I = # ______ cp.

C-175

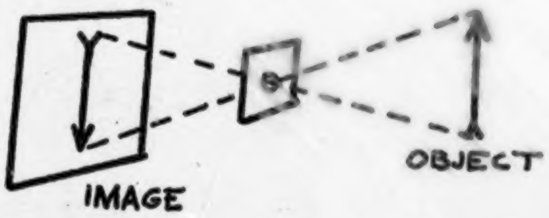
An American named Michelson also measured the speed of light using a rotating mirror. He used a larger distance than Fizeau, 44 miles. In addition, he was able to accurately measure the velocity of light in a vacuum. Like Fizeau and Foucault, Michelson found that the velocity of light was about * ______ or * ______.

C-201

Light travels fastest in a ______, where its velocity is about # ______ kilometers per second or # ______ miles per second.

C-227

Another form of evidence for the straight-line travel, or * ______ of light is that the image of an object will be upside down or ______ if it is projected through a pin-hole.



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END OF UNIT

c-222

luminous intensity
illuminance

c-196

refraction
velocity of light in a vacuum

c-170

tooth
opening
would not

c-144

equal
$(\frac{I}{r^2} =) \frac{I'}{r'^2}$

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67

c-123

luminous intensity
photometry

c-149

5

c-175

300,000 kilometers per second
186,000 miles per second

c-201

vacuum
300,000
186,000

c-227

rectilinear propagation
inverted

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END OF UNIT

C-222

One candlepower of * ____________ equals 12.57 lumens of ____________.

C-196

In studying refraction, it is often helpful to know the index of refraction for each of the media involved. The index of ____________ for any particular optical medium is found by comparing the velocity of light in that medium with c, the * ____________.

C-170

By looking down at the piece of plate glass, Fizeau could see light reflected back to the apparatus from the distant mirror when the wheel was stationary. By rotating the wheel rapidly enough, the pulses of returning light would strike a ________ rather than the ____________ through which the light left, and Fizeau (would/would not) ____________ see the pulses of light.

C-144

If both sides of the photometer are equally bright, E = E'. Since the intensities on each side are equal, the proportions $\frac{I}{r^2}$ and $\frac{I'}{r'^2}$ must also be ____________; that is, when E = E'

$\frac{I}{r^2} =$ $ ________.

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C-124

A photometer (say, foh-tom-eh-ter) is a device used to help us compare the intensity of two light sources. An illuminometer is used to measure the amount of illumination at a surface but a [   ] is used to compare the luminous intensities of two light sources.

C-150

Solve for I when I' = 100 cp, r = 7, and r' = 10; I = [#] cp.

C-176

One reason the accurate measurement of the [   ] of light was so important was that it helped physicists learn how light travels; that is, it helped decide between two important theories of light.

C-202

The speed of light in any other medium is not as great as in a vacuum. In glass, for instance, it is only about 124,000 miles per second. To find the index of refraction for glass, we have to divide 186,000 by 124,000, or $\frac{186,000}{124,000} = \frac{186}{124} =$ [#]. This is μ, the [*] [   ] for glass.

C-228

The amount of light falling on a surface depends on the [*] of the light source and the square of the [   ] between the surface and the light source. The relationship between E, I, and r^2 is known as the inverse [*].

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c-247

faster

a vacuum than it does in glass

c-221

illuminance

c-195

refraction

velocity

c-169

Y

c-143

$E = \frac{I}{r^2}$

luminous intensities (or, candlepowers)

unknown source (or, source of unknown candlepower)

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c-124

photometer

c-150

49

c-176

velocity (or, speed)

c-202

1.5 (or, 3/2)
index of refraction

c-228

luminous intensity
distance
square law

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C-247

Light travels ______ in a vacuum than it does in any medium. The index of refraction for glass is about 1.5 which means light travels 1.5 times as fast in ** ______________________.

C-221

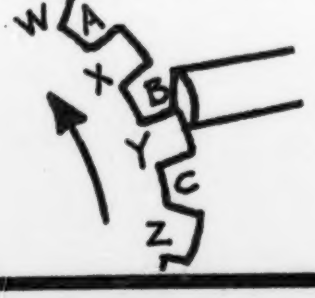
Light flows away from a source in all directions. The amount of light flowing in a given direction is called illuminance. The lumen is the unit of ______.

C-195

Later on, when you study the bending of light, or ______, you will learn that the amount of bending that occurs as light goes from one medium to another depends on the velocity of light in each of the two media. As light goes from air to glass, for example, its speed or ______ changes, and the ray of light will likely be refracted.

C-169

If the wheel were turning, a pulse which left the projector through opening B would not get back to the wheel until the wheel had turned at least a little bit. If the wheel were turning rapidly enough, by the time the pulse of light returned, it would strike tooth $ ______ instead of opening B.



C-143

The inverse square law is written as $ ______. In photometry, there are two sets of illuminations, distances, and * ______ of a source. For the side toward the known source, we write $E' = \frac{I'}{r'^2}$, and for the side toward the * ______, we write $E = \frac{I}{r^2}$.

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C-125

There are several kinds of photometers. One of these is made of a sheet of paper with a grease spot in the center. This is called a Bunsen Photometer. Photometers, such as the "grease spot" or * ____, are used to compare the * ____ of two light sources.

C-151

The efficiency of an electric light bulb is often measured in candlepower per watt. A watt is a measure of electrical energy. The more efficient a bulb is, the more ____ it will produce per watt of electrical energy.

C-177

One theory of light was stated by Newton. He felt light was made up of "corpuscles" (say, core-pus-sels) or small particles. His corpuscular theory of light was that light consisted of particles or ____, much like the bullets coming from a machine gun.

C-203

The formula for index of refraction is $ ____. The speed of light in water is about 140,000 miles per second. Therefore, the index of refraction for water is about # ____.

C-229

As described by the * ____ law, illumination equals intensity divided by the square of the distance, or, in symbols, $ ____.

A·I·R ©1960

c-246

$\mu = \frac{c}{v}$

c-220

candlepower
candle

c-194

velocity (speed) of light
vacuum
300,000
186,000

c-168

B

c-142

the distance from the photometer to the known source (or, r') and to the unknown source (or, r)

A·I·R ©1960

c-125

Bunsen Photometer
luminous intensities

---

c-151

candlepower (or, luminous intensity)

---

c-177

corpuscles

---

c-203

$\mu = \frac{c}{v}$

1.33 (approximately)

---

c-229

inverse square

$E = \frac{I}{r^2}$

A·I·R ©1960

C-246

Write the formula for the index of refraction in symbols, [$].

C-220

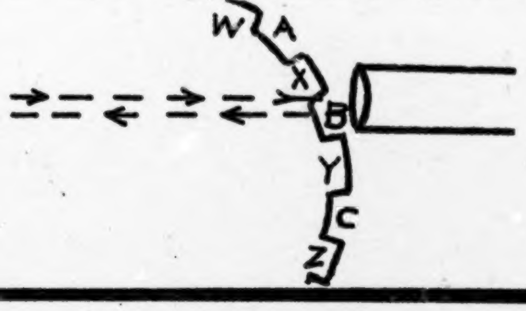
Luminous intensity is measured in units called [ ]. One candlepower is the luminous intensity of a specially made "standard" [ ].

C-194

The symbol "c" stands for the [*] in a [ ]. In kilometers per second, c = [#]. In miles per second, c = [#].

C-168

In this diagram of Fizeau's apparatus, if the wheel were stationary, light which passed through opening B would return from the distant mirror along the same path and would again pass through opening [$].



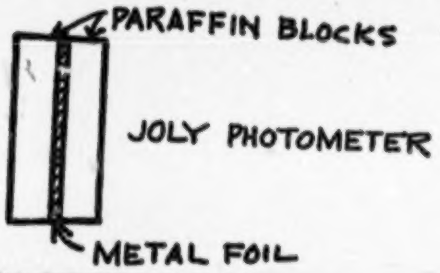
C-142

Once the photometer is positioned so that E = E', the next step is to measure [**].

A·I·R ©1960

C-126

Another kind of photometer is the Joly Photometer, made of two paraffin blocks which are separated by a sheet of metal foil. A photometer, such as the "paraffin block" or [*   ], is used to measure the luminous intensity of a source; that is, it is used in [   ].



C-152

If we divide the candlepower emitted by an electric light bulb by the wattage of the bulb, we determine the [   ] of the bulb.

C-178

Newton's theory was that a beam of light consists of many small particles or [   ]. This was called the corpuscular [*   ].

C-204

To find the index of refraction for a vacuum, c = 186,000 and v would also equal 186,000. Thus, the index of refraction for a vacuum = $\frac{186,000}{186,000}$, or [#   ].

C-230

If the luminous intensity of a source is 75 candlepower and the distance between the source and a surface is 5 feet, the illumination on that surface would be [#   ] foot-candles.

A·I·R ©1960

c-245

index of refraction
velocity of light in a vacuum
velocity of light in another medium

c-219

intensity
luminous intensity

c-193

vacuum
186,000

c-167

opening

c-141

units (or, measures)
units (or, measures)

A·I·R ©1960

⑲

c-126

Joly Photometer
photometry

c-152

efficiency

c-178

corpuscles
theory of light

c-204

1.0

c-230

$(\frac{75}{5^2} = \frac{75}{25} =)\ 3$

A·I·R ©1960

C-245

In the formula $\mu = \frac{c}{v}$, μ stands for the * ______________, c stands for the * ______________, and v stands for the * ______________.

C-219

A very powerful source of light, like the sun, is one which has a high luminous ______________. A very dim source of light, like a candle, has a low * ______________.

C-193

The speed of light in a ______________ is greater than in any other transparent substance. We abbreviate the speed of light in a vacuum with the letter "c." Various experiments have shown that c = 300,000 kilometers per second, or # ______________ miles per second.

C-167

Light which left the projector through an opening would travel to the distant mirror and then back to the apparatus. If the wheel were rotating rapidly enough, however, by the time the pulse of light returned, the light would strike the next tooth in the wheel instead of the ______________ through which it left.

C-141

Inches and centimeters are both ______________ of length. Since, in photometry, we work with proportions, it does not make any difference whether we measure r and r' in inches or in centimeters, so long as we measure both distances using the same ______________.

A·I·R ©1960

C-127

A "grease spot" photometer (Figure 1) is known as a [*]. A "paraffin block" photometer (Figure 2) is known as a [*].

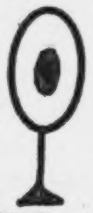


FIG. 1

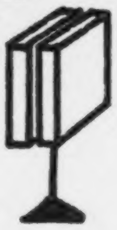


FIG. 2

C-153

A 500 watt light bulb emits about 800 candlepower. The efficiency of this bulb is therefore $\frac{800}{500}$ or [#] cp/watt (say, candlepower per watt).

C-179

The other leading theory of light was developed by a Dutchman named Huygens. His wave theory of light was that light traveled in [ ], much like water waves or sound waves.

C-205

The index of refraction for a vacuum is [#]. Since the velocity of light is greater in a vacuum than in any other medium, v can never be greater than [#] miles per second. Since v is never larger than c, the numerator in the formula $\mu = \frac{c}{v}$ must always be larger than the denominator and therefore, μ can never be (greater/less) [ ] than 1.0.

C-231

Exposure meters and foot-candle meters are both examples of illuminometers. A device used to measure surface illumination is called an [ ].

A·I·R ©1960

c-244

refraction

c-218

vapor
electric current
ultraviolet
emit

c-192

vacuum

c-166

toothed wheel
tooth

c-140

distance to the unknown source (source of unknown candlepower)

A·I·R ©1960

83

c-127

Bunsen Photometer
Joly Photometer

c-153

1.6 (or, 1 3/5)

c-179

waves

c-205

1.0
186,000
less

c-231

illuminometer

A·I·R ©1960

C-244

When we compare the velocity of light in some transparent medium with the velocity of light in a vacuum, we state this as a proportion called the index of ☐.

C-218

In a fluorescent lamp, several processes work together to produce light. First, liquid mercury is heated until it becomes a gas or vapor. Like neon, the mercury ☐ will emit light when we pass an ☐* through it. Most of the light emitted by the mercury vapor is ultraviolet light, which is not visible. But when the ☐ light strikes the special coating inside the tube, the coating will ☐ visible light.

C-192

Light travels faster in a vacuum than it does in any other medium. The velocity of light in a ☐ is greater than it is in water or air or glass.

C-166

Fizeau created pulses of light by rapidly rotating the ☐*. It took a certain amount of time for the light to travel to the distant mirror and back to the apparatus. If the wheel rotated slowly, or not at all, the light would return through the opening through which it left; but if the wheel rotated rapidly enough, the pulse of light would strike a ☐ in the wheel instead of an opening.

C-140

After the photometer has been positioned so that E = E', the distance to the known source, (r'), and the ☐*, (r), can be measured.

A·I·R ©1960

C-128

We cannot measure the luminous intensity of a source directly. Instead, we must compare the light emitted by two sources using a technique called [ ]. To find the candlepower of some source, we have to [ ] its luminous intensity with the luminous intensity of a known or "standard" source.

C-154

A 100 watt light bulb emits about 125 candlepower. The efficiency of this bulb is therefore [#] cp/watt.

C-180

Huygens' [ ] theory of light was that the way light traveled could best be described in terms of [ ] rather than small particles or [ ] as Newton had proposed.

C-206

The index of refraction can never be less than [#]. Actually, the index of refraction tells us how many times faster light travels in a vacuum than it does in some other medium. Knowing that the index of refraction for glass is about 1.5, we know that light travels [#] faster in a [ ] than it does in glass.

C-232

Photometry is the technique of comparing two light sources so as to measure the [*] of a source of unknown candlepower. A photometer is a device used in [ ].

A·I·R ©1960

c-243

bending

---

c-217

incandescent
electric

---

c-191

media
media

---

c-165

mirror

---

c-139

the illumination on one side (facing the source of unknown candlepower) is equal to the illumination on the other side (facing the source of known candlepower) (or, both sides are equally illuminated)

A·I·R ©1960

c-128

photometry
compare

c-154

1.25 (or, 1 1/4)

c-180

wave
waves
corpuscles

c-206

1.0
1.5
vacuum

c-232

luminous intensity
photometry

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C-243

The fact that light has different velocities as it travels through different media is important in discussing refraction, the ______ of light as it passes from one optical medium to another.

C-217

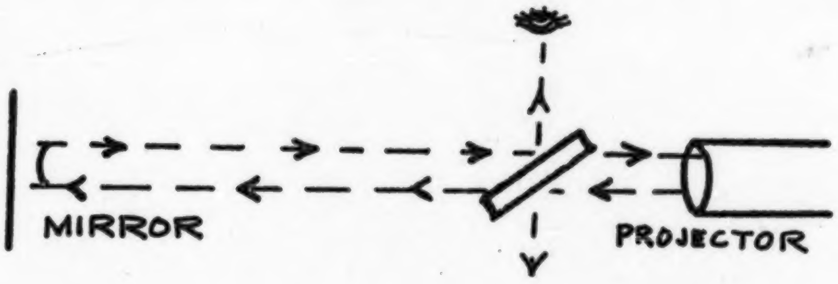
A neon sign does not depend on heat to produce light; it is not an ______ source of light. Neon gas will give off light when we pass an ______ current through it.

C-191

The plural of the word medium is media. Light can have different velocities in different media. Light does not travel as fast in some ______, such as water, as it does in other ______, such as air.

C-165

By looking down at the plate glass, Fizeau would see only the light which was returning from the ______ on a hilltop several miles away.



C-139

When the two sides of the photometer appear equally bright, we know E = E'; that is,

** ______________________________

____

______.

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C-129

Photometry is the ** ☐. We find the luminous intensity of a source of unknown candlepower by ** ☐, with the help of a device called a ☐.

C-155

The more efficient a particular electric light bulb is, the more candlepower per watt it produces. A bulb which produces 1.3 cp/watt is (more/less) ☐ efficient than one which produces 1.1 cp/watt.

C-181

On the basis of his ☐ theory of light, Newton said light would travel faster in water than in air. On the basis of his ☐ theory of light, Huygens said light would travel slower in water than in air.

C-207

The index of refraction for water is about 1.33. This means that the velocity of light is 1.33 times (faster/slower) ☐ in a vacuum than it is in ☐.

C-233

A photometer helps us ☐ the luminous intensity of an unknown source with that of a known source. We place the photometer between the two sources and adjust its position until each side of the photometer is equally ☐.

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c-242

wave theory (of light)
corpuscles

c-216

tungsten
incandescent

c-190

medium

c-164

upward

c-138

the two sides (both sides) of the photometer are equally illuminated

A·I·R ©1960

c-129

measurement of the luminous intensity of a source
comparing it with the luminous intensity of a source with known candlepower
photometer

c-155

more

c-181

corpuscular
wave

c-207

faster
water

c-233

compare
illuminated

A·I·R ©1960

C-242

The finding that light traveled faster in air than in water suggested Huygens' * ____________ was more accurate than Newton's theory that light consisted of small particles or ____________.

C-216

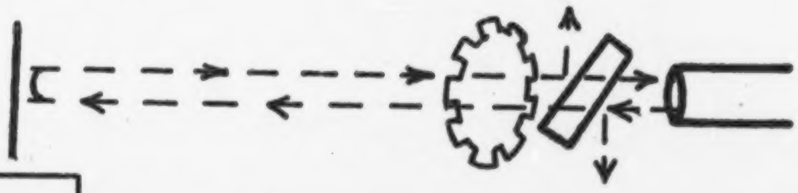
Most of the light bulbs we use today are tungsten filament lamps. Since the filaments in these bulbs give off light when they are heated, a ____________ filament lamp is an ____________ source of light.

C-190

The amount of refraction or bending which will occur as light goes from one optical medium to another depends on the difference in the velocity of light in one optical ____________ as compared with the velocity of light in the other.

C-164

So that he could observe the light as it returned from the mirror on the hilltop, Fizeau placed a piece of glass at an angle between the projector and the wheel. Some light, coming from the projector was reflected downward off the surface of the glass and some of the light returning from the distant mirror was reflected ____________.



C-138

The first step in photometry, using a Joly Photometer, is to adjust the position of the photometer until ** ____________.

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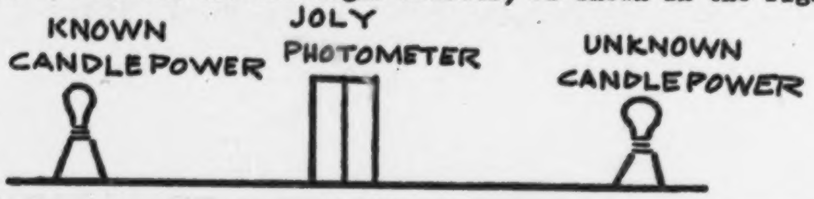
C-130

To find the luminous intensity, or candlepower of a source, we compare the light it emits with that emitted by a "standard" source; that is, one with known ________. To use a Joly Photometer, we place it between the two light sources, as shown in the figure.



C-156

A 200 watt light bulb emits about 290 cp, and a 1000 watt light bulb emits about 1640 cp. Since the efficiency of the 200 watt bulb is # ________ cp/watt, it is (more/less) ________ efficient than the 1000 watt bulb which has an efficiency of # ________ cp/watt.

C-182

Newton's corpuscular theory and Huygens' wave theory differed as to whether light would travel faster in air or in water. From his corpuscular theory, ________ predicted the velocity of light would be highest in water. From his wave theory, ________ predicted the velocity of light would be * ________.

C-208

The index of refraction for air is about 1.003. This means that light travels only slightly faster in ** ________.

234

We usually let E, I and r^2 stand for the measurements of the unknown source, and E', I' and r'^2 stand for the measurements of the * ________. In photometry, we first adjust the ________ until both of its sides are equally illuminated; that is, so E = $ ________.

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c-241

300,000
186,000
c

---

c-215

heated
incandescent

---

c-189

light can travel (pass)
refracted

---

c-163

opening

---

c-137

E
illumination
illumination on the side facing the source of known candlepower

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c-130

candlepower (or, luminous intensity)

c-156

1.45
less
1.64

c-182

Newton
Huygens
higher in air (lower in water)

c-208

a vacuum than it does in air

c-234

known source
photometer
(E =) E'

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C-241

The velocity of light in a vacuum is about [#] kilometers per second or [#] miles per second. We use a symbol to stand for the speed of light in a vacuum, the letter [$].

C-215

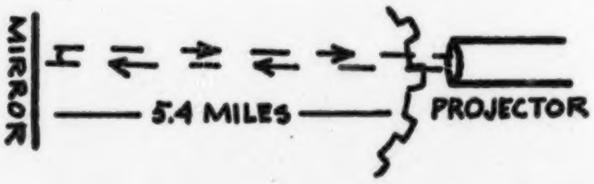
Incandescent sources of light are those which emit light because they are [ ]. The sun and an electric light bulb are both [ ] sources of light.

C-189

An optical medium is any transparent substance; that is, any substance through which [*]. As light goes from one optical medium to another, it may be bent or [ ].

C-163

The pulses of light were projected through the toothed wheel to a mirror on a hilltop about 5 miles away. When the mirror was properly adjusted, the pulses of light were reflected back along the same path. When the wheel was not rotating, light would leave the projector, pass through an [ ] in the wheel and then return through the same opening.



C-137

Illumination is represented by the letter [$]. In photometry, we first adjust the photometer; that is, move it toward one of the sources, until the illumination of either side of the photometer is equal; that is, we adjust the photometer until E = E', where E stands for the [ ] on the side facing the source of unknown candlepower, and E' stands for the [**].

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C-131

As a paraffin block is moved closer to a light source, it will receive greater illumination and appear brighter. We know this from the inverse square law, that illumination is directly proportional to the * ______ of the source and inversely proportional to the square of the ______ to the source.

C-157

Geometrical optics is the study of how light travels from place to place. So far, with equal respect to how light travels, you have learned about rectilinear propagation; that is, light travels in * ______.

C-183

According to the corpuscular theory of light developed by ______, light would travel faster in water than in air. According to the wave theory of light developed by ______, light would travel slower ** ______.

C-209

Since the velocity of light in air and a vacuum are so close, we usually use the same numbers as the velocity of light in each. Thus, the speed of light in air, as well as in a vacuum, is usually given as # ______ miles per second, or # ______ kilometers per second.

C-235

When we have made E = E', we measure r, the distance to the unknown source, and r', the * ______.

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c-240

velocity
measured
toothed wheel

---

c-214

radiant energy

---

c-188

refracted

---

c-162

opening
tooth

---

c-136

unknown candlepower (or, unknown luminous intensity)

86

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c-131

luminous intensity
distance

c-157

straight lines

c-183

Newton
Huygens
in water than in air

c-209

186,000
300,000

c-235

distance to the known source

A·I·R ©1960

C-240

The speed or ________ of light is finite; that is, it can be ________. The first person to measure the speed of light using a source on the earth was Fizeau. He projected short pulses of light through the openings in a * ________ to a distant mirror.

C-214

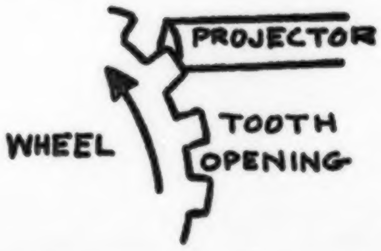
Light is a form of radiant energy. Heat and radio waves are also forms of * ________.

C-188

The fact that light travels faster in air than in water is also important in another way. It helps explain why light is bent or refracted as it passes from one transparent substance to another; that is, it helps explain why light is bent or ________ by a magnifying glass or lens.

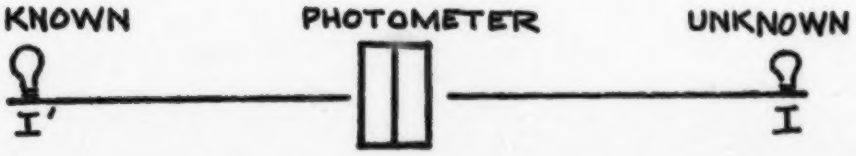
C-162

To get his pulses of light, Fizeau projected a strong beam of light through openings between the teeth of a rapidly rotating wheel. Light would be projected where there was an ________ in the wheel, but no light would be projected if a ________ was in the path of the beam.



C-136

In photometry, there are two light sources and two distances involved. One of the sources is of known candlepower, I' (say, I prime), and the other a source of * ________, I.



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C-132

When a Joly Photometer is placed between two light sources, the side which appears brighter is the one receiving the most [ ] on its surface. If both sides appear equally bright, we know that the surfaces on each side are (equally/not equally) [ ] illuminated.

C-158

The way shadows are formed, and the fact that images projected through a pin-hole are inverted, are both evidence for the straight-line travel or [*] of light.

C-184

Foucault, using his rotating mirror apparatus, was able to test the predictions about the velocity of light in air and water. He found that the velocity of light was higher in air than in water; that is, that light traveled (faster/slower) [ ] in air than in water.

C-210

Knowing the index of refraction for a particular substance, we can find how fast light travels in it. Since the index of refraction for water is 1.33, the speed of light in water is $\frac{300,000}{1.33}$ kilometers per second, or [#] kilometers per second.

C-236

When $E = E'$, we know that $\frac{I}{r^2} = \frac{I'}{r'^2}$. Thus, by knowing I', r' and r, we can calculate I, the [*] of the [*].

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c-239

efficiency

1.33

c-213

natural

artificial

c-187

air

water

waves

particles

corpuscles

c-161

measured

c-135

$E = \frac{I}{r^2}$

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(103)

c-132

illumination
equally

c-158

rectilinear propagation

c-184

faster

c-210

225,564

c-236

luminous intensity
unknown source

A·I·R ©1960

C-239

The efficiency of an electric light bulb is measured by how many candlepower it produces per watt of electrical energy. A 75 watt bulb that produced 100 cp has an ______ of #______ cp/watt.

C-213

The sun and a fire are examples of (natural/artificial) ______ sources of light, while an electric light bulb and a neon sign are examples of (natural/artificial) ______ sources of light.

C-187

The fact that light travels faster in ______ than in ______, supports Huygens' theory that light travels in ______ and does not support Newton's theory that light travels as small ______ called ______.

C-161

Fizeau decided to measure the speed of light by seeing how long it would take for a short pulse of light to go from one point to another and back. Because light travels so rapidly, however, he had to develop a special apparatus. He wanted to show that the speed or velocity of light was finite; that is, it could be ______.

C-135

In symbols, the inverse square law is written as $______.

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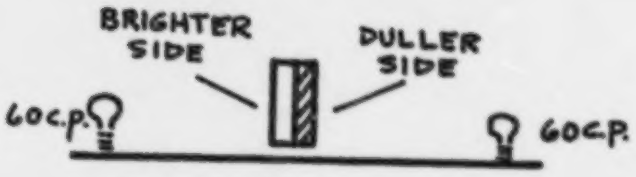
C-133

If a Joly Photometer is placed in between two light sources of equal candlepower, the side of the photometer which appears brighter is the one (nearer to/farther from) ______ one of the two light sources.



C-159

The study of the velocity, or speed, of light is another problem in geometrical optics. Although light travels very, very fast, its speed, or ______, can be measured.

C-185

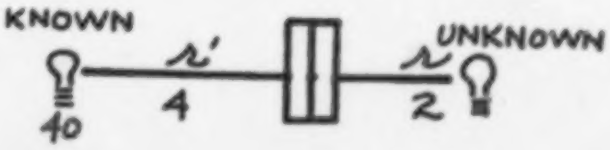
Foucault discovered that the ______ of light was greater in air * ______ ______. His discovery supported Huygens' * ______; that is, he found that Huygens' theory was more correct than ______ corpuscular theory of light.

C-211

The index of refraction for glass is about 1.5. Since $\mu = \frac{c}{v}$, the velocity of light in glass is about # ______ kilometers per second.

C-237

When the photometer has been adjusted so that E = E', we can find I. If I' = 40, r' = 4, and r = 2, we can substitute in the formula $\frac{I}{r^2} = \frac{I'}{r'^2}$, or, $\frac{I}{2^2} = \frac{40}{4^2}$. Then, $\frac{I}{4} = \frac{40}{16}$, $I = \frac{160}{16}$, so I = # ______.



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c-238

$$\left(\frac{108}{6^2} = \frac{I}{2^2},\ \frac{108}{36} = \frac{I}{4},\ \frac{432}{36} = I =\right)\ 12\ \text{cp}$$

c-212

optics

c-186

corpuscular theory (of light)
Huygens' wave theory (of light)

c-160

velocity

c-134

greater

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c-133

nearer to

---

c-159

velocity

---

c-185

velocity
than in water
wave theory (of light)
Newton's

---

c-211

200,000

---

c-237

(I =) 10

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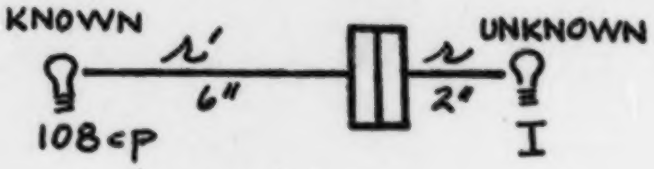
C-238

If the luminous intensity of the standard source is 108 cp, and when E = E', r is 6 inches and r' is 2 inches, I= # cp.



C-212

In physics, the study of light is called optics. How light originates and how it travels are both part of ☐.

C-186

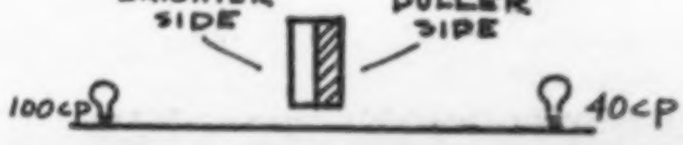
On the basis of experiment such as the one done by Foucault, we now assume Newton's * is not as correct as ** .

C-160

A Frenchman named Fizeau (say, Fizz-oh) was the first person to accurately measure the speed of light terrestrially (on the earth). He was the first person to clearly demonstrate that the speed, or ☐ of light was finite; that is, that it could be measured.

C-134

If a Joly Photometer is placed between two light sources of unequal candlepower, but at an equal distance from each one, the side of the photometer which appears brighter is the one facing the light source of (greater/lower) ☐ light intensity.



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UNIT THREE

REFLECTION OF LIGHT, IMAGE FORMATION
AND MUTIPLE REFLECTION

Steps C-248 through C-367

BEGIN UNIT HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

UNIT ENDS HERE

C-248

Light travels in straight lines, but it "bounces" when it strikes a shiny surface. This bouncing of light from a shiny surface is called reflection. When a ray of light strikes a shiny surface, such as a mirror, ________ will occur.

C-272

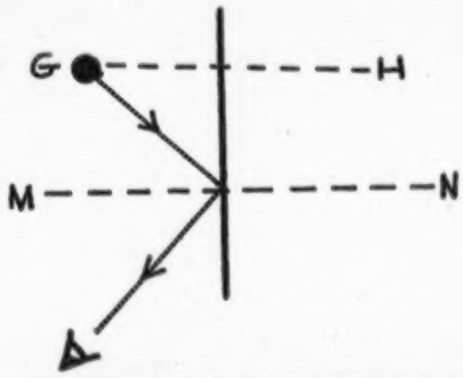
The angle at which the incoming ray strikes the surface is called the * ________ ________. It is formed by two lines; one representing the * ________ and the other representing the ________.

C-296

In both diffuse reflection and specular reflection, the angle of incidence equals the * ________. In symbols, this law of ________ is stated as $ ________.

C-320

The imaginary line drawn perpendicular to the surface at the point an incident ray touches the surface is called a ________. A line drawn from the object perpendicular to the ________ is also called a normal. In this figure, two normals have been drawn, one is line $ ________ and the other is line $ ________.



C-344

A real image is formed where rays of light intersect. You will learn more about real images when you study curved mirrors and lenses. This kind of image, which is actually made up of light rays; that is, a ________ image, is different from the image seen in a flat mirror which is a ________ image.

A·I·R ©1960

c-367

farther away
smaller

c-343

virtual

c-319

reflected ray

c-295

diffuse reflection
reflected rays
normals

c-271

incidence
0 (zero)

A·I·R ©1960

c-248

reflection

---

c-272

angle of incidence
incident ray
normal

---

c-296

angle of reflection
reflection
$i = i'$

---

c-320

normal
surface
GH (MN)
MN (GH)

---

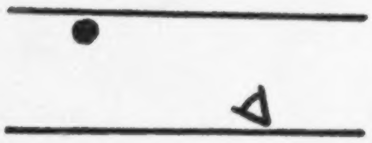
c-344

real
virtual

A·I·R ©1960

C-367

When an object and the eye are both between parallel mirrors, as in the figure, the eye will see many images. Some of these images are the result of light from the object being reflected back and forth between the mirrors several times. The farther the light has to actually travel to reach the eye for any given image, the (nearer/farther away) ☐ that image will appear to be, and the (larger/smaller) ☐ the image will seem.

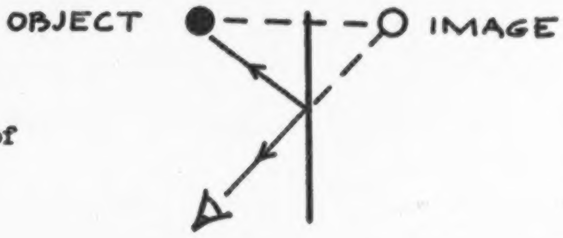


C-343

The image seen in a flat mirror is not formed where rays of light actually meet. The image is actually an imaginary object located behind the mirror. We call these images virtual images. The image of our own face seen in a mirror is a ☐ image.

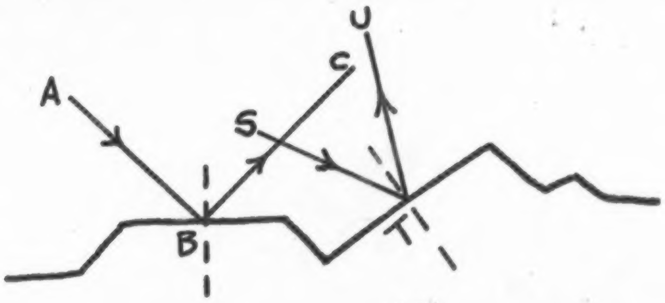
C-319

To find the location of the image of an object reflected in a plane mirror, we draw a line perpendicular to the mirror. The image is located where this line intersects with a straight line extension of the path of light from the surface to the eye; that is, with an extension of the path of the ☐ * .



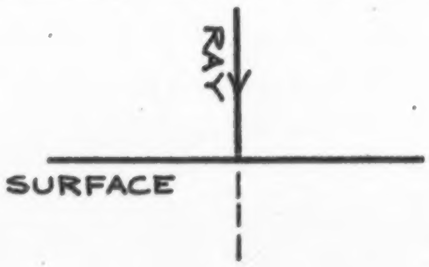
C-295

Here is another figure showing reflection from a rough surface, or ☐ * Incident rays AB and ST are parallel but ☐ * BC and TU are not, nor are the ☐ represented by dotted lines.



C-271

If the incident ray is along the same line as the normal; that is, when the incident ray and the normal overlap, there is no angle between them. We call this an angle of ☐ of ☐ # degrees.



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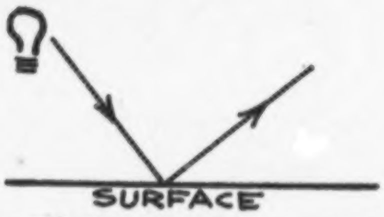
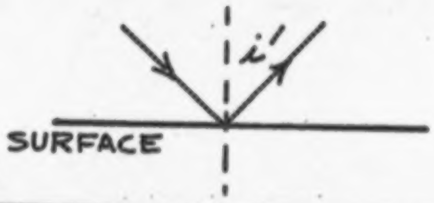
C-249

The change in the direction of a ray of light as it strikes a shiny surface is called ________. The figure shows the ________ of a ray of light.



C-273

The angle formed by the normal and the reflected ray is called the angle of reflection. In the figure, the angle labeled i' (say, i-prime) is the * ________.

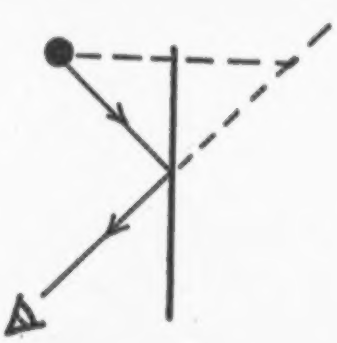


C-297

When light is reflected off a smooth surface, such as a mirror, this is called * ________. When light is reflected off a rough surface, such as sandpaper, this is called * ________.

C-321

The image is located where a line drawn from the ________ and perpendicular to the ________ intersect with an extension of the * ________. Draw a small circle in this figure to show where the image is located.



C-345

There are two kinds of images. One is formed where rays of light intersect; this is called a ________ image. The other kind of image which is located where the rays of light seem to be coming from is called a ________ image. The image seen in a flat mirror is a ________ image.

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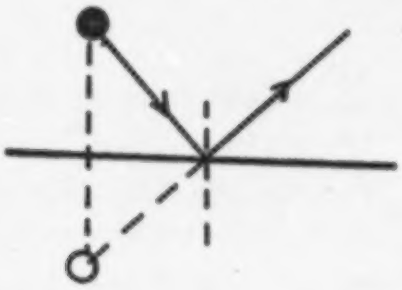
c-366

images
object

c-342



c-318

7
straight
7
behind

c-294

rough

c-270

normal
surface

A·I·R ©1960

c-249

reflection
reflection

c-273

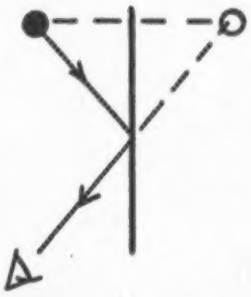
angle of reflection

c-297

specular reflection
diffuse reflection

c-321

object
surface (or, mirror)
reflected ray



c-345

real
virtual
virtual

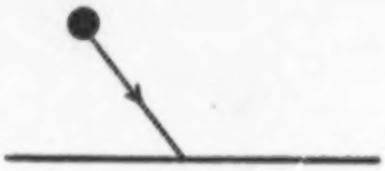
A·I·R ©1960

C-366

When looking at the images formed when an object is placed between two mirrors, we can see that many of the images have been reflected back and forth between the mirrors several times. That is, many of the images seen in one mirror are actually the reflection of other ☐ from the other mirror and are not reflections of the ☐ itself.

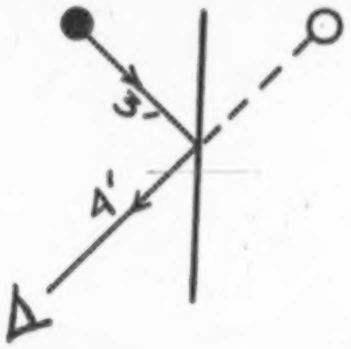
C-342

For this figure, draw a normal where the incident ray strikes the surface. Draw a reflected ray, and locate the image. Use a circle to designate the image.



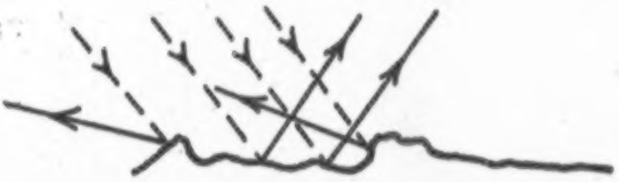
C-318

In this figure, the image will appear to be # feet away. Since we see the image as if the light traveled in a ☐ line, the image will appear to be # feet from our eye, but ☐ the mirror.



C-294

This figure illustrates diffuse reflection; that is, reflection from a ☐ surface. Each ray of light is reflected, but the reflected rays are not all parallel.



C-270

When there is a small angle of incidence, as in Figure 1, the incident ray is very close to the ☐. When there is a large angle of incidence, as in Figure 2, the incident ray is close to the reflecting ☐.

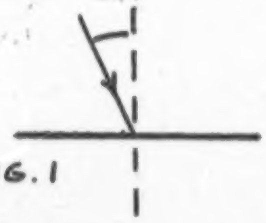


FIG. 1

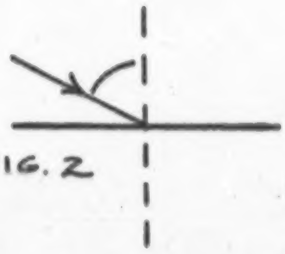


FIG. 2

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C-250

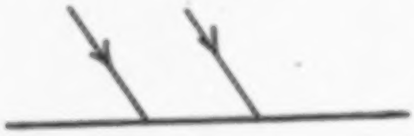
Reflection occurs whenever a ray of light strikes a shiny surface. Reflection is the [*] of a light ray as it strikes a [*].

C-274

The angle of reflection is formed by the [ ] and the path of the light going away from the surface; that is, the [*].

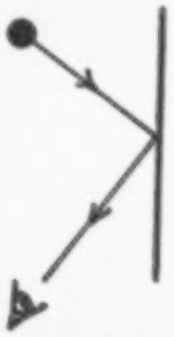
C-298

In this figure, two incident rays have been drawn. Draw in normals and reflected rays for each incident ray. Normals are parallel to each other in [ ] reflection but are not all parallel to each other in [ ] reflection.



C-322

Locate the image in this figure, drawing the necessary lines and drawing the image as a small circle.



C-346

Reflection is the [ ] of light rays as they strike a shiny [ ].

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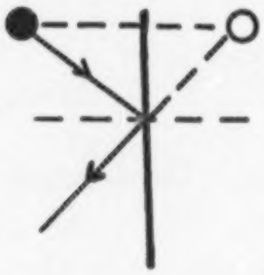
c-365

straight
virtual

c-341



c-317

55

c-293

diffuse

c-269

small

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c-250

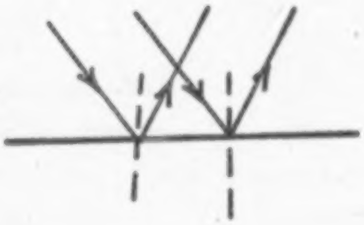
change of direction (or, bouncing, bending)
shiny surface

c-274

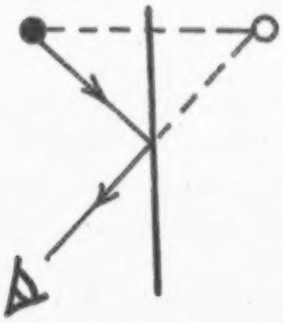
normal
reflected ray

c-298

specular
diffuse



c-322



c-346

bouncing (or, bending)
surface

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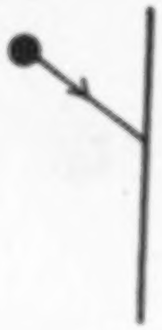
C-365

No matter how many mirrors are involved in getting the light to our eye, the eye still sees the image as if the light traveled to the eye in a ☐ line. Since the image is imaginary; that is, it is not actually formed by the intersection of light rays, we call the images seen in a flat mirror ☐ images.

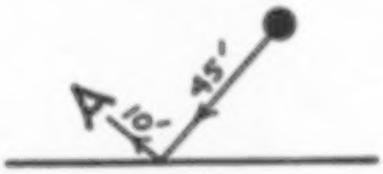
C-341

For this figure, draw a normal where the incident ray strikes the surface. Draw a reflected ray, and draw the lines necessary to locate the image. Use a circle to designate the image.



C-317

When we see the image of an object in a mirror, the image seems to be as far away from our eye as the total distance the light had to travel. This object will appear to be # feet from our eye.

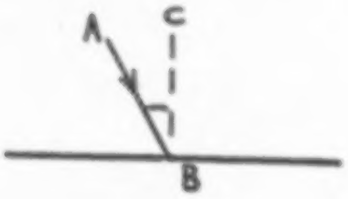


C-293

Reflection from a rough surface is called diffuse (rhymes with "juice") reflection. A great deal of light is reflected from a white sandy beach, but since the surface is rough, it is ☐ reflection.

C-269

To measure an angle of incidence, we begin our measurement at the normal. Line AP is close to the normal CB, the angle of incidence is (small/large) ☐.



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C-251

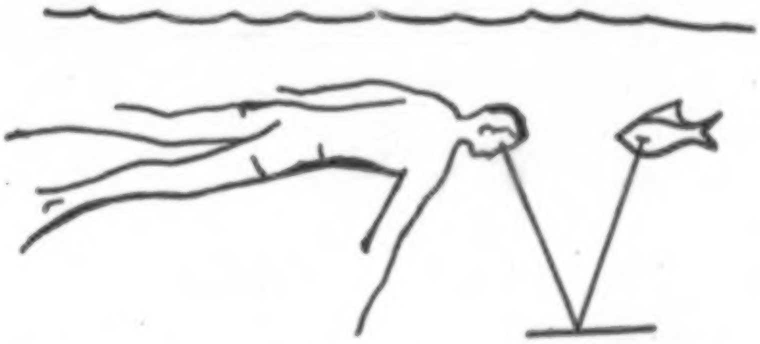
Light has rectilinear propagation; that is, it travels in * ______.
We know, then, that the path of the outgoing ray of light, as well as the path of the incoming ray of light, will be a straight line.

C-275

Like the angle of incidence, the angle of reflection is measured in degrees beginning at the normal. For example, a 20° angle of reflection would be (nearer/farther from) ______ the normal than an angle of reflection of 60°.

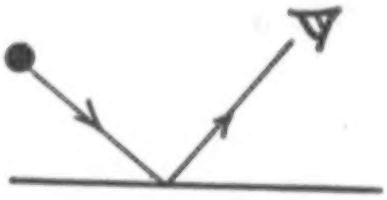
C-299

Reflection can occur while light is traveling in any medium or substance. A swimmer underwater can observe the reflection of light. Here too, the angle of ______ equals the * ______.



C-323

Locate the image in this figure, drawing the necessary lines and drawing the image as a small circle.



C-347

The law of reflection is that the ** ______ ______ and that both the ** ______ ______.

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c-364

increased (or, larger)

---

c-340

behind
object
straight
reflected

---

c-316

mirror
eye
7

---

c-292

smooth (and shiny) surface
specular

---

c-268

incident
normal

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c-251

straight lines

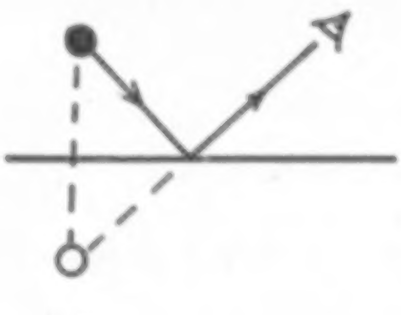
c-275

nearer

c-299

incidence (reflection)
angle of reflection (incidence)

c-323



c-347

angle of incidence equals the angle of reflection
incident ray and reflected ray are in the same plane.

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C-364

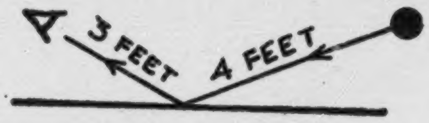
As the angle between two mirrors is made smaller, the number of images of an object placed between them which can be seen by the eye will be [ ].

C-340

The image seen by looking at a mirror seems to be as far [ ] the mirror as the [ ] is in front of the mirror. The image appears as if the light came to our eye in a [ ] line, along an extension of the [ ] ray.

C-316

When we see the reflected image of an object, the light from that object must travel the distance to the mirror, and then the distance from the [ ] to our [ ]. In this figure, the light must travel a total of [#] feet.



C-292

Specular reflection means reflection from a [*]. The reflection of sunlight off a well polished automobile is an example of [ ] reflection.

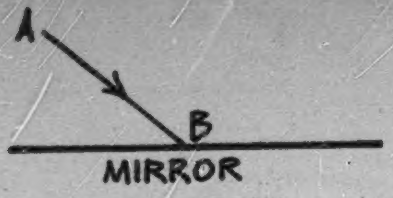
C-268

The angle of incidence is the angle formed between the [ ] ray and the [ ].

A·I·R ©1960

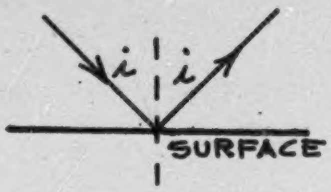
C-252

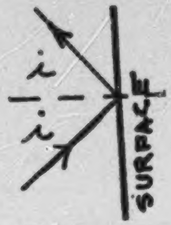
The ray of light which travels toward a reflecting surface is called an incident ray. In the figure, line AB represents an * ________ because it travels toward a ________ surface.



C-276

In these figures, i stands for the * ________ and i' stands for the * ________. The dotted line in both figures is the ________.



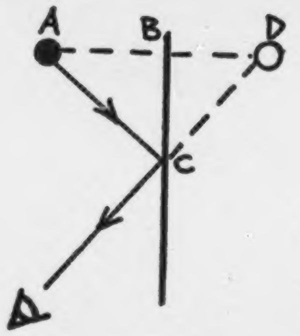


C-300

When we look into a mirror or other reflecting surface, we see an image. A mirror allows us to see an ________ of some object.

C-324

Using plane geometry, it is possible to prove that triangle ABC is identical to triangle BCD; that is, that the angles in ABC are the same as those in BCD, and the lengths of the sides of ABC are ________ to those in triangle $ ________.



C-348

Multiple reflection means that the ray of light has been reflected more than once in coming to our eye from the object. If the ray of light strikes several mirrors before reaching our eye, * ________ has occurred.

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c-363

less

c-339

angle of reflection
reflected ray
plane

c-315

smaller

c-291

specular

c-267

angle of incidence

(131)

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c-252

incident ray
reflecting (or, mirror)

c-276

angle of incidence
angle of reflection
normal

c-300

image

c-324

identical
BCD

c-348

multiple reflection

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C-363

Mirrors placed at a large angle to each other (Figure 1) will result in the eye seeing (more/less) ______ images of an object placed between them than if the angle were smaller (Figure 2).

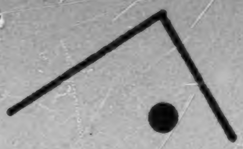


FIG. 1

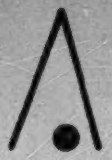


FIG. 2

C-339

The law of reflection states that in reflection from a flat, specular surface, the angle of incidence equals the * ______ and that the incident ray and * ______ are both in the same ______.

C-315

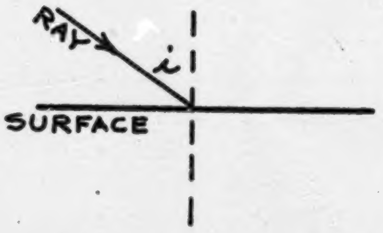
The farther light has to travel to reach our eye, the smaller it seems to be. An object placed 50 feet away from us would appear ______ than if it were placed only 10 feet away.

C-291

So far, we have only illustrated reflecting surfaces that were smooth like a plate glass mirror or a polished table top. Reflection from a smooth surface is called specular (say, spek-u-lar) reflection. When a light strikes a smooth shiny surface, ______ reflection occurs.

C-267

To describe the path of the incident ray of light, we measure the angle between the incident ray and the normal. In the figure, the symbol "i" stands for the * ______.



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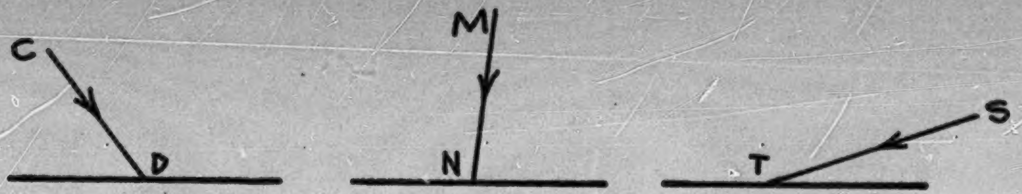
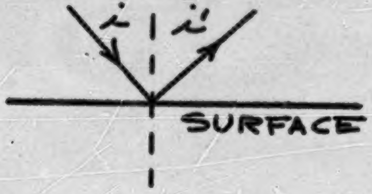
C-253

An incident ray is a ray of light which travels ** ________________.
In the figures, lines CD, MN and ST are all examples of ________ rays.



C-277

The law of reflection states that, whenever reflection occurs, the angle of incidence equals the angle of reflection. In symbols, this law can be stated, i = $ ______.

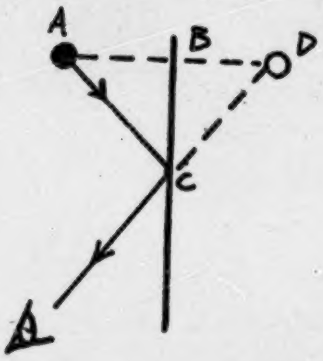


C-301

We can see an object if light rays coming from that object strike our eye. If the object is luminous, like the sun, we know it is emitting the light we see. If the object is not luminous we know it must be ________ light which originated elsewhere.

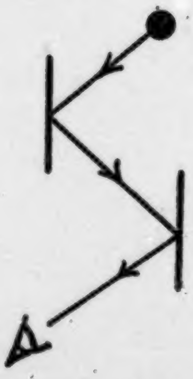
C-325

The triangles ABC and BCD are identical. This means the length of side AC equals the length of side DC, and the length of side AB equals the length of side $ ______.



C-349

In this figure, the light has been reflected twice; that is, * ________________ has occurred.



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c-362

images

c-338

specular

diffuse

c-314

smaller

c-290

zero

c-266

90

angle

A·I·R ©1960

c-253

toward a reflecting surface
incident

---

c-277

$(i =)\ i'$

---

c-301

reflecting

---

c-325

BD

---

c-349

multiple reflection

A·I·R ©1960

C-362

When the angle between two mirrors is large, the eye will see only a few images of an object placed between the mirrors. But as the angle between the mirrors is made smaller, the number of ☐ that can be seen increases.

C-338

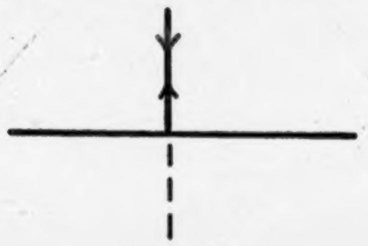
A clear image will be seen by looking at a smooth, or ☐, surface such as a mirror. Reflected light, but no clear image, will be seen by looking at a rough, or ☐, surface such as cardboard.

C-314

The farther an object is from our eye, the smaller it seems to be. While flying in an airplane, the automobiles we see on the ground appear much ☐ than they appear when we are close to them.

C-290

In the drawing, the incident ray strikes perpendicular to the surface. Both the angle of incidence, and the angle of reflection will be ☐ degrees. The light leaving the surface will take exactly the same path as it did when it approached the surface.



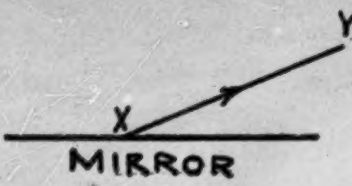
C-266

Two lines perpendicular to each other intersect at an angle of ☐ # degrees. An angle of 5° or 10°, like the one in the figure, is a very small ☐. Sometimes we speak of an angle of 0° (zero degrees). This is when the two lines making up the angle overlap, and appear as one line.

A·I·R ©1960

C-254

The ray of light which travels away from a reflecting surface is called a reflected ray. In the figure, line XY represents a * ______ because it travels away from a ______ surface.



C-278

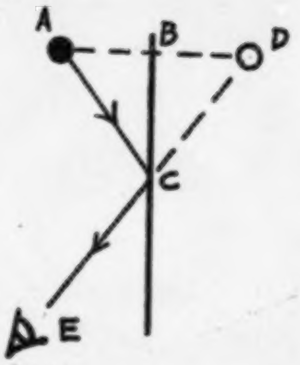
The law of ______ states that the angle of incidence equals the angle of reflection. For example, if the angle between the incident ray and the normal were 40°, the angle between the ** ______ would also be # ______ degrees.

C-302

We can see objects which either emit light or * ______ which was ______ somewhere else. The flame of a candle ______ light, but the wax part of a candle ______ light that originated elsewhere.

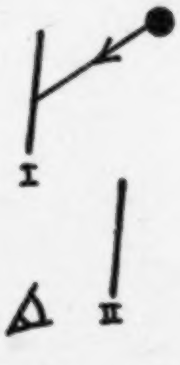
C-326

Since triangles ABC and BCD are identical, we know that the object is as far in front of the mirror (line AB) as the image is ______ the mirror (line BD). We also know the path of light from the object to our eye (ACE) is the same length as the straight line from our eye to the ______ (ECD).



C-350

In this figure, an incident ray has been drawn from the object to mirror I. Draw the normal, and draw a reflected ray to mirror II.



A·I·R ©1960

c-361

several images (more than one image)

---

c-337

smooth
rough
object

---

c-313

behind

---

c-289

normal (or also, reflected ray)
0 (zero)

---

c-265

normal
angle

A·I·R © 1960

(139)

c-254

reflected ray
reflecting (or, mirror)

---

c-278

reflection
reflected ray and the normal
40

---

c-302

reflect light
emitted
emits
reflects

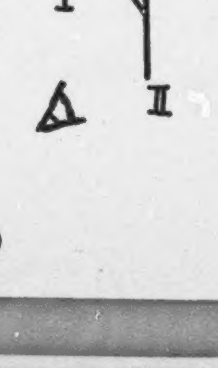
---

c-326

behind
image

---

c-350



A·I·R ©1960

C-361

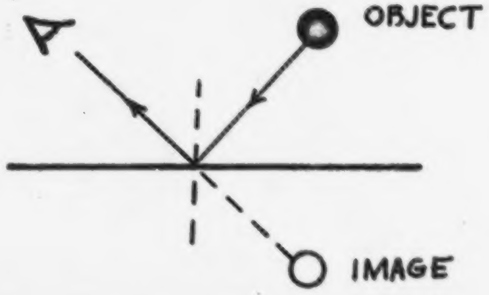
When two mirrors are placed at an angle to each other, the eye will see [*] in addition to seeing the object itself.

C-337

So far, the images studied have been those formed by reflection from a specular, or [ ], surface. Reflection from a diffuse, or [ ], surface does not produce clear images. This is because the image formed behind the surface does not correspond perfectly to the [ ] in front of the surface.

C-313

Light from an object which is reflected in a plane or flat mirror seems to come to our eye in a straight line. The image seems to be located [*], in a straight line extension of the reflected ray.

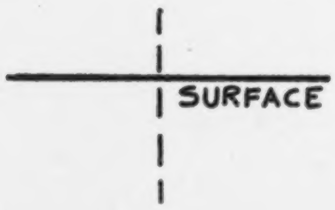


C-289

If a light ray strikes a surface at zero degrees of incidence, we know that the incident ray coincides with the [ ]. We also know that the angle of reflection, which equals the angle of incidence, must also be [#] degrees.

C-265

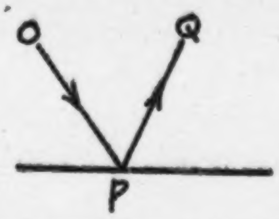
An imaginary line drawn perpendicular to a reflecting surface is called a [ ]. If the surface is flat; that is, if it is a plane surface, we can easily see that this line makes an [ ] of 90° with the surface.

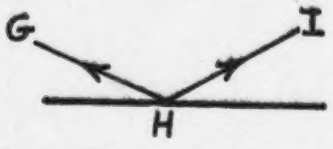


A·I·R ©1960

C-255

A reflected ray is a ray of light which travels ** ________ ________. In the figures, lines PQ and GH are both examples of ________ rays.



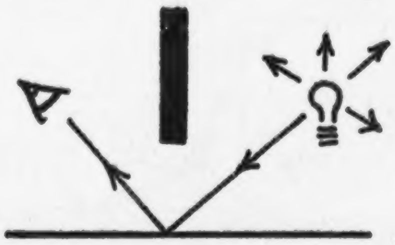


C-279

If we increase the angle of incidence, we also ________ the angle of reflection, because these two angles are always the same. If we decrease the angle of incidence, we ** ________ by the same amount.

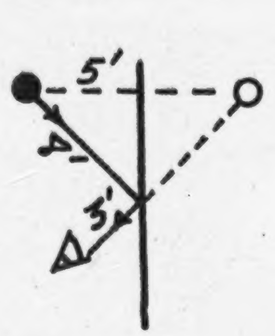
C-303

In this figure, the eye sees the ________ of a point source of light reflected in the mirror.



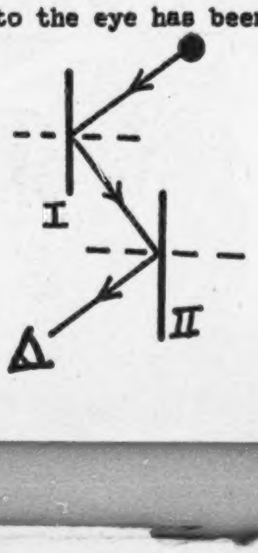
C-327

In this figure, the object is 5 feet in front of the mirror. The image will appear to be # ________ feet behind the mirror. The path the light took to reach our eye is 8 + 3, or 11 feet. The image will seem to be # ________ feet from our eye.



C-351

In this figure, the complete path of light from the object to the eye has been drawn. Notice that the reflected ray for mirror I is the ________ ray for mirror II.



A·I·R ©1960

c-360

several

---

c-336

object is in front of it

---

c-312

behind the mirror
side of the mirror

---

c-288

perpendicular
incidence

---

c-264

perpendicular

A·I·R ©1960

c-255

away from a reflecting surface
reflected (rays)

c-279

increase
decrease the angle of reflection

c-303

image (or, reflection)

c-327

5
11

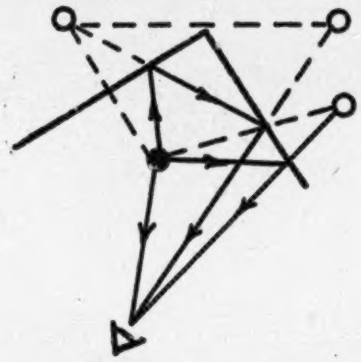
c-351

incident

A·I·R ©1960

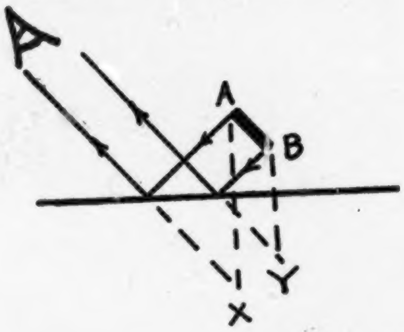
C-360

In this figure, two mirrors have been placed at an angle to each other, and an object placed between them. As shown by the figure, the eye will see (one/several) ____ images in addition to seeing the object by looking at only one mirror.



C-336

Now join points X and Y with a heavy line. This is the image that would be seen of object AB. The image is as far behind the surface as the * ____ ____.

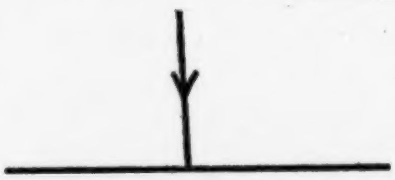


C-312

An image formed by reflection from plane (or, flat) surfaces is located * ____; that is, on the other side of the mirror from our eye. The object is on the same * ____ as our eye.

C-288

If an incident ray is perpendicular to a surface, it coincides with the normal, which is also ____ to the surface. There is no measurable angle of incidence in this case; that is, the angle of ____ is zero degrees.



C-264

Angles are measured in degrees, abbreviated by the symbol °. Figure 1 shows an angle of 30°, Figure 2, one of 60°, and Figure 3, one of 90°. A 90° or "right" angle is formed when the two lines making up the sides of the angle are ____.

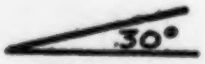


FIG. 1

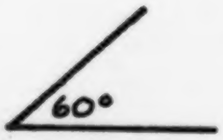


FIG. 2

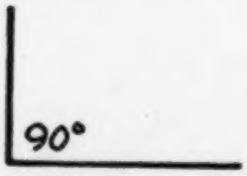
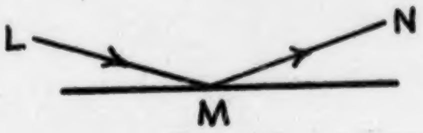


FIG. 3

A·I·R ©1960

C-256

In the drawing, the incident ray (from the light source to the surface), is shown as line $ ____. The reflected ray (the path of light after reflection) is shown by line $ ____.

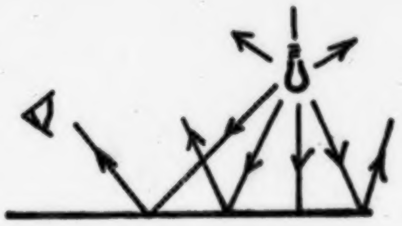


C-280

According to the law of reflection, the angle of ____________ equals the angle of ____________. In addition, the incident ray and reflected ray are in the same plane, which means the reflected ray does not turn off to one side.

C-304

A source of light emits light in all directions. When we see the image of a source in a mirror, however, we only see those rays of light which strike the mirror at the particular angle for the light to strike our eye. Other rays of light strike the ____________, but they do not all reflect so as to strike our ________.

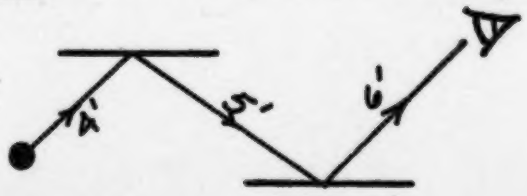


C-328

In reflection from a plane surface, the image seems to be as far away from our eye as the distance along the ____________ ray from the object to the mirror plus the distance along the ____________ ray from the mirror to our eye. It also seems to be as far behind the mirror as the ** ______________________________.

C-352

Even when more than one flat mirror is involved, the image appears to be along a straight line from our eye, as far away as the sum of the distances light has traveled from the object. In this figure, the light has traveled a total of # ______ feet, so the image will appear to be # ______ feet away.

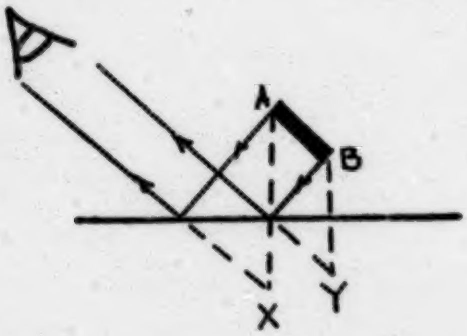


A·I·R ©1960

c-359

image
farther away from

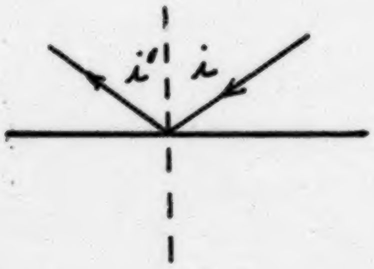
c-335



c-311

behind (or, in back of)
in front of the mirror

c-287



c-263

angle

A·I·R ©1960

c-256

LM
MN

c-280

incidence (reflection)
reflection (incidence)

c-304

mirror
eye

c-328

incident
reflected
object is in front of the mirror

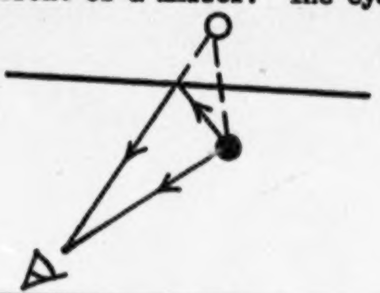
c-352

15
15

A·I·R ©1960

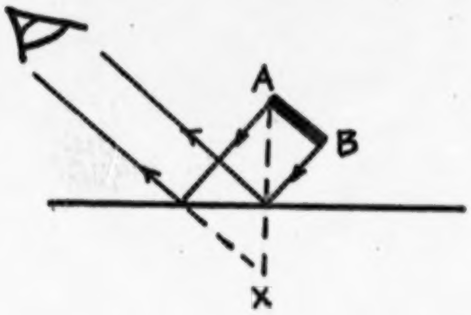
C-359

In this figure, an object has been placed in front of a mirror. The eye will see both the object and, as shown in the figure, one ☐. The image will appear (closer/farther away from) ☐ the eye than the object.



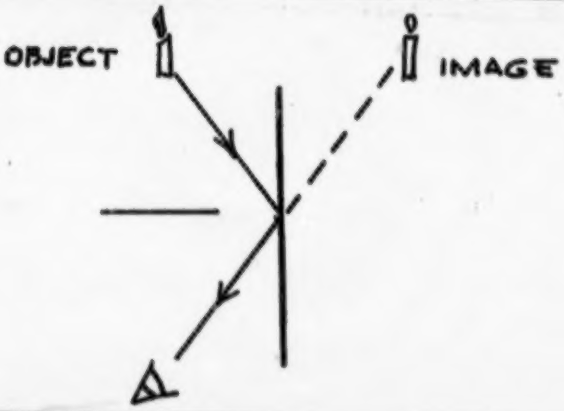
C-335

Now show where an image point corresponding to object point B would be located. Mark it with a Y.



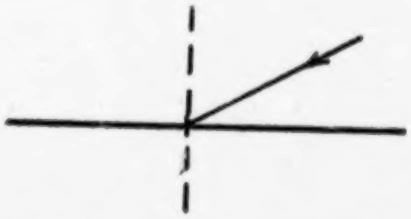
C-311

A reflected image is located where the light seems to be coming from. In reflection, the image is located ☐ a flat mirror even though the object is located ☐ ** .



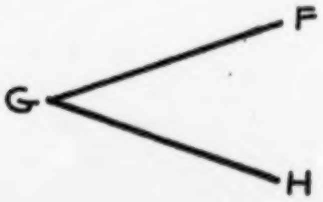
C-287

In this figure, the incident ray is coming in from the right, and makes an angle of about 60° with the normal. Draw the reflected ray and label the angle of incidence i and the angle of reflection i'.



C-263

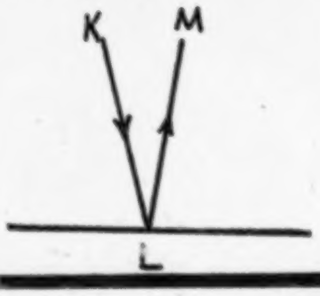
An angle is formed wherever two lines meet or intersect. In this figure, lines FG and GH form an ☐.



A·I·R ©1960

C-257

The figure shows the path of a ray of light as it strikes and is bent away from a reflecting surface. Line KL is the ________ ray and line LM is the ________ ray.



C-281

The reflected ray is in the same plane as the incident ray, which means the reflected ray does not turn off to one side. Figures 1 and 2 show these rays in the same ________ . Figure 3 shows the rays in (the same plane/ different planes) ________ .

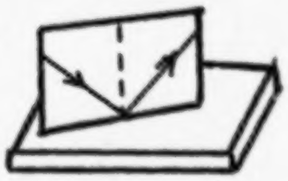


FIG. 1

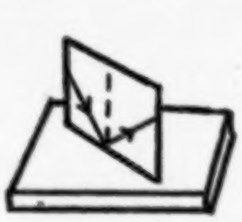


FIG. 2

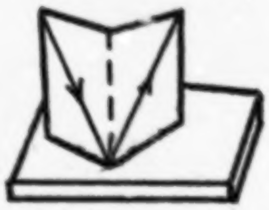
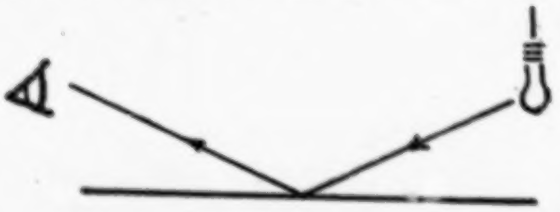


FIG. 3

C-305

This figure shows the path of light which comes to our eye from a point on the object after being reflected in a mirror. Draw a normal and label the angle of incidence i and the angle of reflection i'.

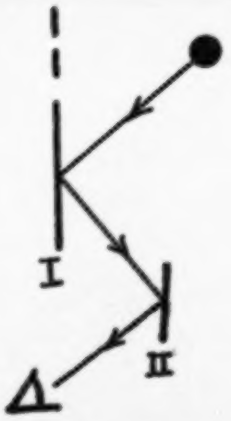


C-329

It can also be shown by geometry that the path taken by the light from the object to the mirror to our eye is the shortest path. That is, if the figure is properly drawn, not only will the angle of ________ equal the * ________ , but the sum of the lengths of the incident ray and reflected ray will show the path taken by the light, was the ________ possible path.

C-353

To locate the image in multiple reflection, first locate the image for the mirror nearest the object. In this figure, extend the reflected ray back through mirror I and draw a normal from the object. Indicate the image with a circle.



A·I·R ©1960

c-358

periscope

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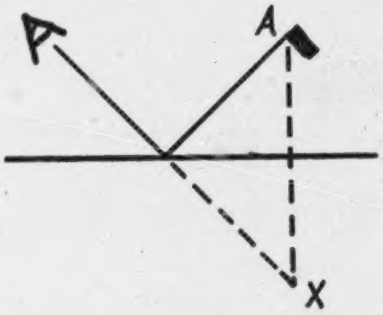
c-334



---

c-310

behind

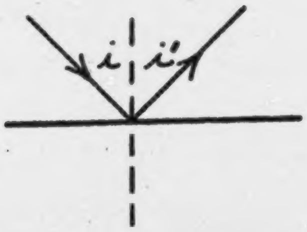
X

---

c-286

angle of reflection

45



---

c-262

incident ray

normal

reflected ray

A·I·R ©1960

⑮

c-257

incident
reflected

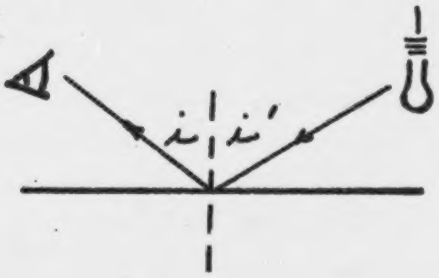
---

c-281

plane
different planes

---

c-305



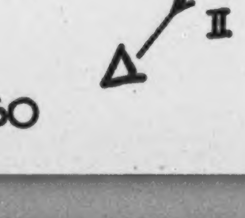
---

c-329

incidence
angle of reflection
shortest

---

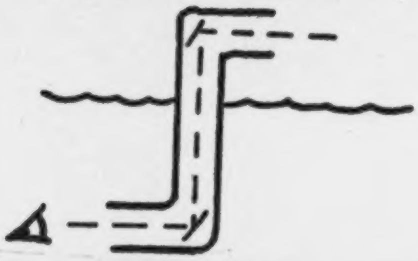
c-353



A·I·R ©1960

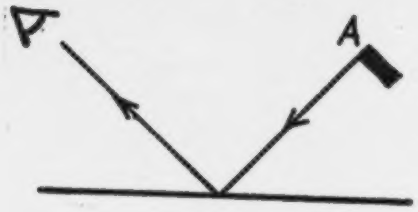
C-358

A device which can be made of two mirrors, which allows a man in a submarine to see what is happening on the surface of the ocean is called a ______.



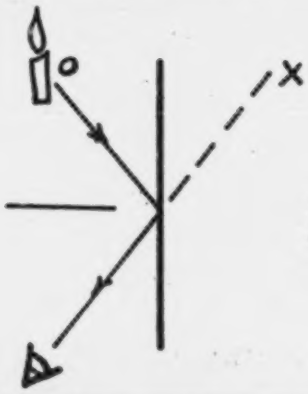
C-334

In this figure, an incident ray of light is shown coming from one point (A) on an object. Draw lines to show where the corresponding point of the image would appear. Mark the point with an X.



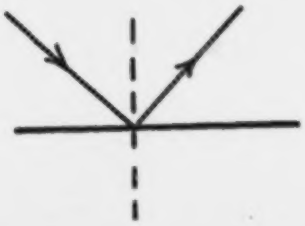
C-310

When we see the image of an object reflected in a mirror, it appears as if the light came from ______ the mirror. In the figure, the object O would appear as if it were located at point $ and we were seeing it through a piece of glass.



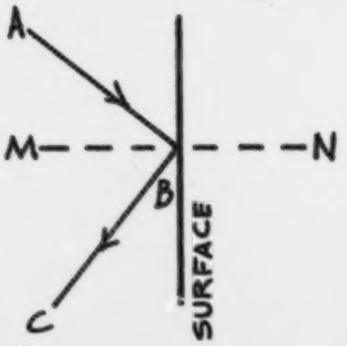
C-286

In this figure, the angle of incidence is 45°, so we know that the * ______ must also be # degrees. Label the angle of incidence with an i and the angle of reflection with an i'.



C-262

In this figure, line AB is an * ______, line MBN a ______, and line BC a * ______.



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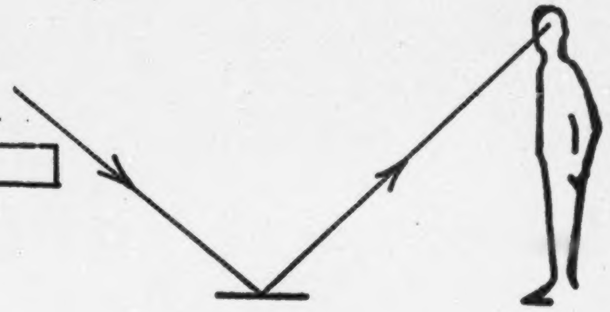
C-258

This man sees a bright object on the ground. The light that strikes his eye is reflected sunlight. The ray of light from the sun to the object is called the [*] and the ray of light from the object to the man's eye is called the [*].

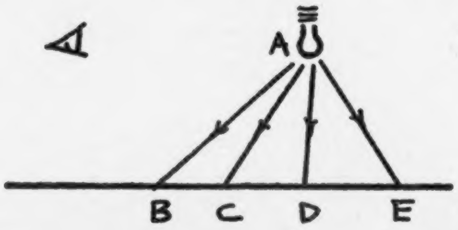


C-282

The law of reflection states that the angle of [**] and that both the incident ray and reflected ray are in the same [ ].

C-306

Four incident rays are shown, but only the reflected ray corresponding to incident ray [$] will strike the eye.

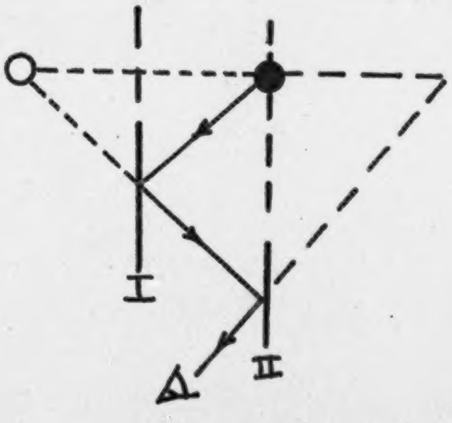


C-330

The fact that light takes the shortest possible path in reflection from a plane surface is called Fermat's Principle of Least Time (say, Fair-mah'z, which rhymes with "he has"). Any other path, according to [ ] Principle of [*], would be longer.

C-354

Now, to find the image seen in mirror II, we treat the image from mirror I as the [ ] for mirror II. Indicate the image for mirror II with a circle.



A·I·R ©1960

c-357

periscope

c-333

incidence does not equal (is smaller than) the angle of reflection
Principle of Least Time
shortest

c-309

behind (or, in back of)

c-285

the angle of incidence equals the angle of reflection
are in the same plane

c-261

perpendicular
incident
normal

A·I·R ©1960

c-258

incident ray
reflected ray

c-282

incidence (reflection) equals the angle of reflection (incidence)
plane

c-306

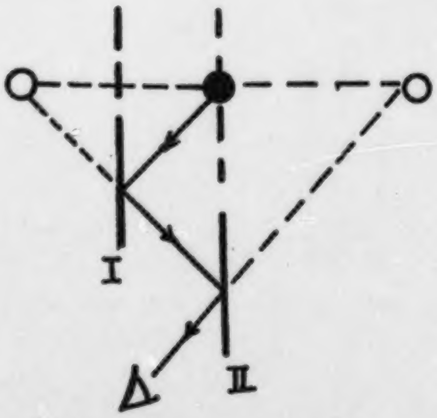
AC

c-330

Fermat's
Least Time

c-354

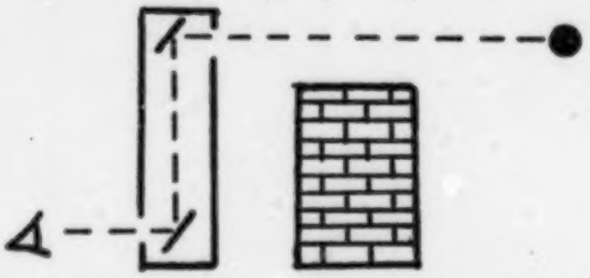
object



A·I·R ©1960

C-357

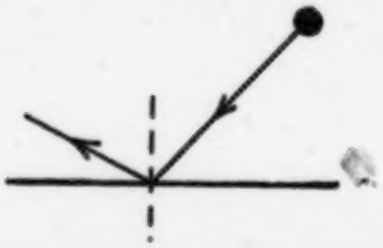
A simple, mirror periscope consists of two mirrors placed at 45° angles. As shown in the figure, by looking through a ________ we can see over a wall or around corners.



C-333

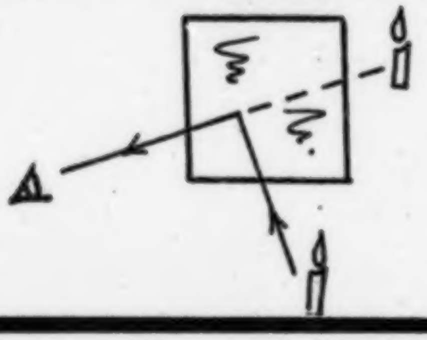
This figure shows an incident ray and a reflected ray which have been drawn incorrectly. They are incorrect because the angle of ** ________ ________.

According to Fermat's * ________ ________, the path drawn is not the ________ possible path.



C-309

When we see an image in a mirror, the object we see seems to be behind the mirror, as if we were looking at it through a piece of glass. It appears to our eye that light rays from the object have traveled to us in a straight line, from a place ________ the mirror to our eye.

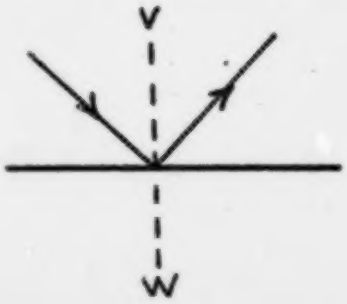


C-285

The law of reflection is that ** ________ ________ and that both the incident ray and the reflected ray ** ________ ________.

C-261

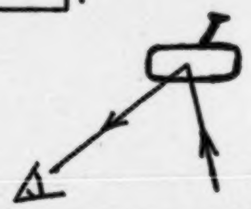
A normal is always drawn ________ to the surface at the point where the incoming, or ________, ray strikes the surface. Line VW in this figure is a ________.



A·I·R ©1960

C-259

A man sees the auto behind him when he looks in the rear view mirror of his car. The ray of light from the other auto to the mirror is called an [*] and the one from the mirror to the man's eye is called a [*].



C-283

For each of these two figures, draw a normal and a reflected ray. Use an arrow to indicate the direction of light in the reflected ray.

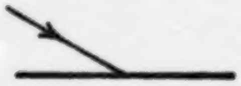


FIG. A

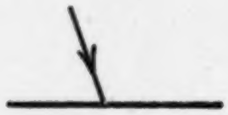
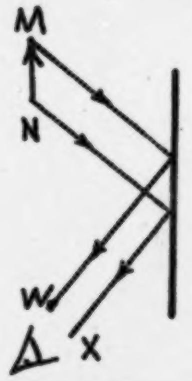


FIG. B

C-307

This figure shows two incident rays leaving an object at the angle of incidence necessary to strike the eye. The ray which left object point M will strike our eye at point [$] and the ray which left object point N will strike our eye at point [$].

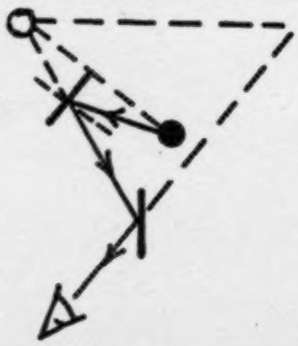


C-331

According to Fermat's [*], light reflected to our eye has taken the [*]. According to [ ] then, the length of any other combination of incident ray and reflected ray would travel a longer [ ].

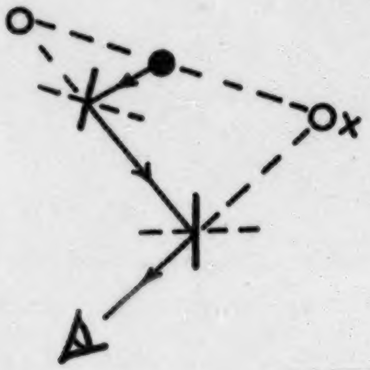
C-355

In this figure, the mirrors are not parallel. Draw a circle to indicate where the image seen by the eye will seem to be located.



A·I·R ©1960

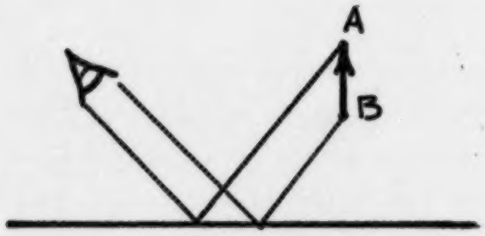
c-356



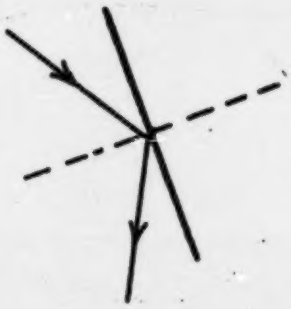
c-332

Fermat's
Least Time
angle of reflection
reflected ray
shortest

c-308



c-284



c-260

normal

A·I·R ©1960

c-259

incident ray

reflected ray

c-283

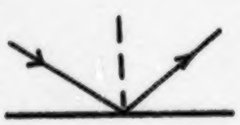


FIG. A

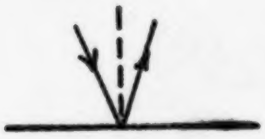


FIG. B

c-307

W

X

c-331

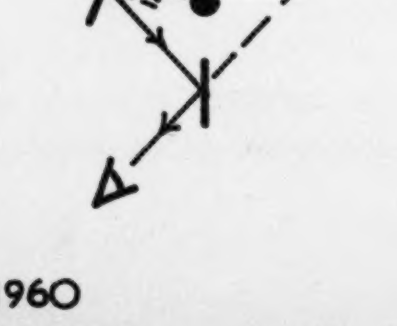
Principle of Least Time

shortest possible path

Fermat

path

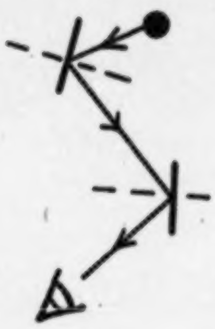
c-355



A·I·R ©1960

C-356

Locate the two images for this figure. Draw the image seen by the eye as a circle and label it X.

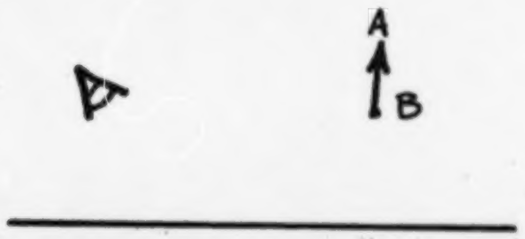


C-332

As stated by [ ] Principle of [*], when the angle of incidence equals the [*], the path taken by the incident ray and the [*], is the (shortest/longest) [ ] possible path.

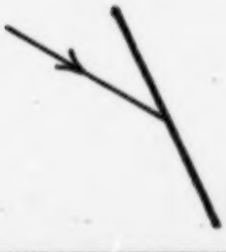
C-308

Complete this figure to show the rays of light leaving object point A and B which will strike the mirror and be reflected to our eye.



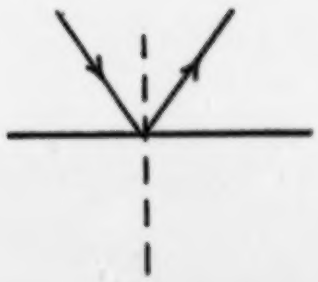
C-284

Draw a normal and a reflected ray for this figure. Use an arrow to indicate the direction of light in the reflected ray.



C-260

In order to accurately describe the reflection of a light ray, we use an imaginary line drawn perpendicular to the reflecting surface at the point where reflection occurs. This line is called a normal. The figure shows a [ ] drawn where the light strikes the surface.



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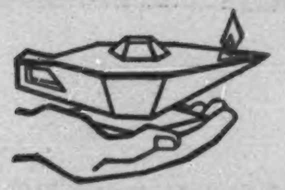
UNIT FOUR

REFLECTION FROM CURVED SURFACES

Steps C-368 through C-522



BEGIN UNIT HERE

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CONTINUE HERE

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CONTINUE HERE

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CONTINUE HERE

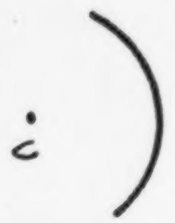
UNIT ENDS HERE

C-368

You have learned how images are formed in reflection from plane surfaces; that is, when the shiny surface is flat. Reflection will also take place when light strikes a shiny curved surface. Reflection can occur from both flat, or ☐ surfaces, and from ☐ surfaces.

C-400

Draw three different normals to the surface of this spherical mirror.

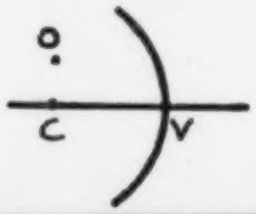


C-432

A virtual image is where rays of light appear to be coming from when seen by the eye. A real image is where rays of light actually intersect. A plane mirror forms a virtual image, but a concave mirror may produce either a virtual or a ☐ image, depending on where the object is placed.

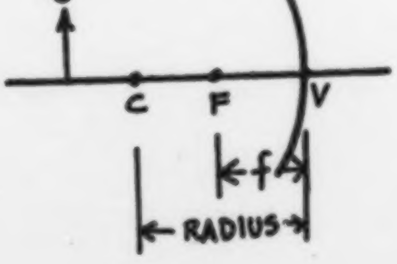
C-464

The two lines you have thus far learned to use for locating an image point are a line through C; that is, a ☐ * and a line parallel to the principal axis which is reflected through the ☐ *. When an object point is directly above or below C, as in the figure, however, a secondary axis will not touch the ☐ of the mirror.



C-496

If the radius of curvature of a spherical mirror, that is, the distance from point C to point V, was 8 inches, we know the focal length must be half that length, or ☐ # inches. Then, if an object was 12 inches from the vertex, the image distance equals, that is, the image would be formed, ☐ # inches from the ☐.



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c-495

object distance (image distance)
image distance (object distance)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

c-463

focal point
real
inverted
larger

c-431

secondary
AB (or, BA)
B
A

c-399

center of curvature
principal axis
secondary axis

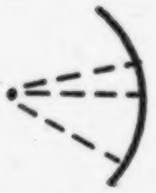
A·I·R ©1960

c-368

plane
curved

c-400

(any three lines from point C to the surface of the mirror would be correct)



c-432

real

c-464

secondary axis
focal point
surface

c-496

(f=) 4

$(\frac{1}{4} = \frac{1}{12} + \frac{1}{d_1},\ \frac{1}{4} - \frac{1}{12} = \frac{1}{d_1},\ \frac{2}{12} = \frac{1}{d_1};\ d_1 = \frac{12}{2} =)\ 6$

vertex

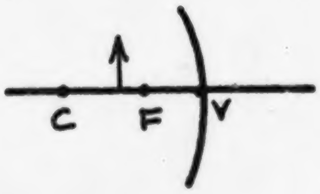
A·I·R ©1960

C-495

The object distance, the image distance, and the focal length of a spherical mirror are related. If we know any two of these measurements, we can find the third. We could find the focal length, providing that we knew the * ____ and the * ____ ____ using the formula $ ____ .

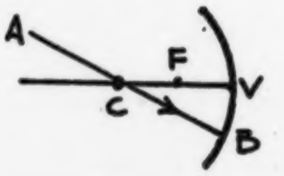
C-463

In this figure, the object is placed between point C, the center of curvature, and F, the * ____ . By locating and drawing the image, you can see it is a (real/virtual) ____ image, that it is (upright/inverted) ____ , and that it is (larger/smaller) ____ than the object.



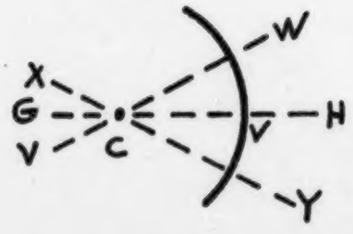
C-431

This figure shows the path of an incident ray going from point A to point B. Since line AB is also a ____ axis, the reflected ray will also travel along line $ ____ , from point $ ____ back to point $ ____ .



C-399

To draw a normal to a spherical mirror, we draw a line from the * ____ ____ to the surface. This is always either ~~the~~ * ____ , line GH, or a * ____ , as line VW or XY.



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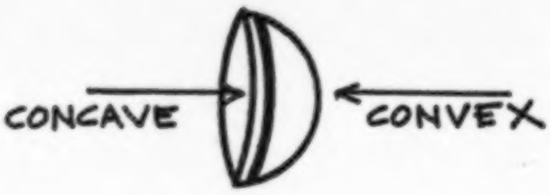
C-369

A curved surface may be either concave or convex. A shiny metal bowl is an example of a curved reflecting surface. The inside of the bowl is the concave surface; the outside or bottom of the bowl is the convex surface. The side that is "cut in," like a cave is called the ☐ surface.



C-401

In studying rays of light, we describe them as diverging or moving apart (figure 1), converging or moving together (figure 2), or parallel (figure 3). Light rays (diverge/converge) ☐ in all directions from a point source of light.

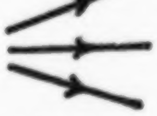


FIG. 1

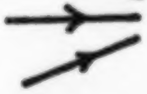


FIG. 2

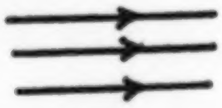
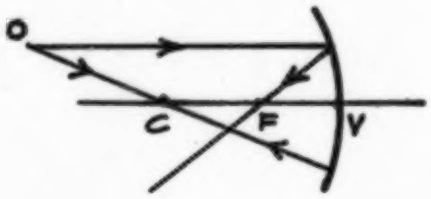


FIG. 3

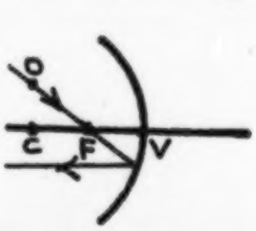
C-433

An image point for a virtual image is where the rays of light seem to be coming from. An image point for a real image is where the light rays coming from any particular object point intersect. Two rays of light leaving object point O intersect after reflection. Label this point "I."



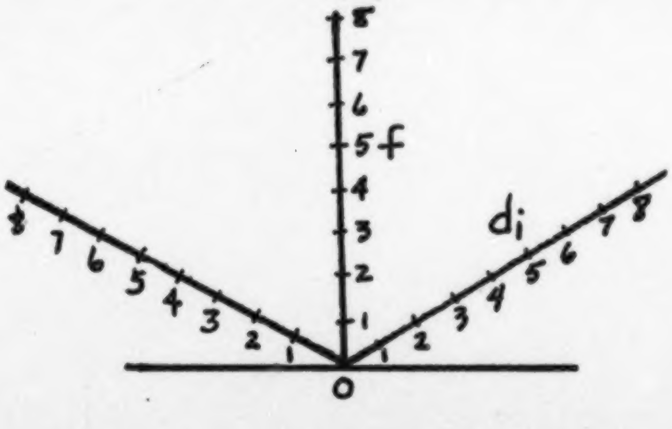
C-465

The location of an image point can also be found using a line drawn through the focal point. You know that if a ray of light is parallel to the principal axis, it will be reflected so that it then passes through the ☐ *. A ray which passes through F before striking the surface, will be reflected along a path which is ☐ to the principal axis.



C-497

Sometimes we can use a chart or graph instead of algebra to solve an equation. This kind of graph is called a nomograph. The figure shows the ☐ that can be used instead of the formula $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$.



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c-494

$(\frac{1}{d_i} = \frac{1}{3} - \frac{1}{6} =)\ \frac{1}{6}$

$(d_i =)\ 6$

c-462

real
inverted
smaller

c-430

surface
the same

c-398

principal axis
secondary axis (or, radius of curvature)

A·I·R ©1960

c-369

concave

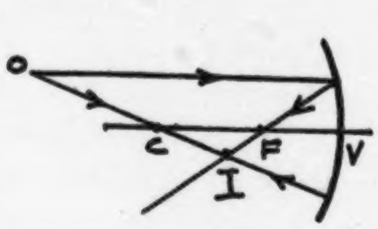
---

c-401

diverge

---

c-433



---

c-465

focal point
parallel

---

c-497

nomograph

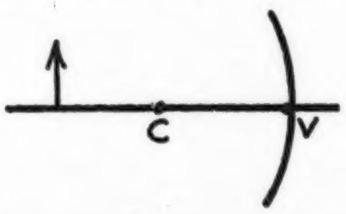
A·I·R ©1960

C-494

If f is 3, and d_o is 6, $\frac{1}{d_i}$ = # and d_i = #.

C-462

In this figure, the object is placed farther from the mirror than C, the center of curvature. By locating and drawing the image, you can see it is a (real/virtual) ☐ image; that is, it is (upright/inverted) ☐, and that it is (larger/smaller) ☐ than the object.



C-430

For curved surfaces, the principal axis and any secondary axis are perpendicular to the ☐ of the mirror. A ray of light traveling toward the mirror's surface along one of these paths will be reflected back along (the same/a different) ☐ path.

C-398

In reflection from curved surfaces, a normal is always either the * or a *.

A·I·R ©1960

C-370

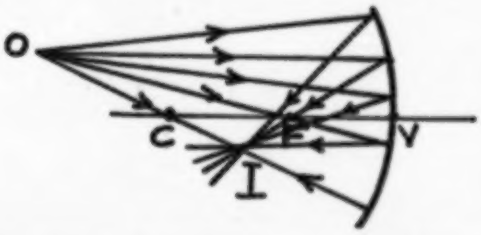
A spoon has curved surfaces. The bottom of the spoon is a convex surface, but the inside of the spoon is a ______ surface. When we "cup" our hand, we have formed a curved surface. The inside or palm of our hand is a ______ surface, but the back of our hand is a ______ surface.

C-402

Light rays which seem to be moving toward one point are said to be converging. Light rays which seem to be moving away from one point are said to be ______. Light rays which are neither diverging nor ______ are said to be parallel.

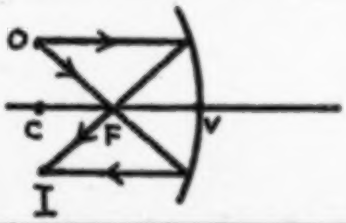
C-434

Light diverges in all directions from any one object point. All these rays which strike a curved mirror will converge toward one point, the corresponding ______ point.



C-466

A ray which passes through the focal point while traveling from the object to the mirror will be reflected along a path which is ** ______. This line can be used to locate the image point when the object point is right above or below point C. In such cases, the image point will be located directly opposite the object point, on the other side of the * ______.



C-498

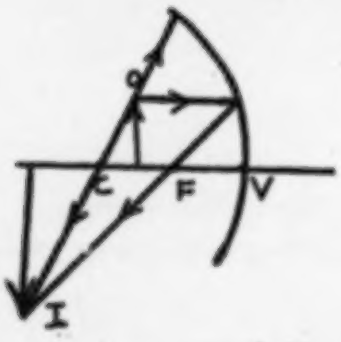
The kind of graph used to find the answer to a problem involving an unknown which does not require the use of algebra is called a ______.

A·I·R ©1960

c-493

$(\frac{1}{f} =)\ \frac{1}{d_o} + \frac{1}{d_1}$

c-461



c-429

path
reflected ray

c-397

normal
normal

A·I·R ©1960

c-370

concave
concave
convex

c-402

diverging
converging

c-434

image

c-466

parallel to the principal axis
principal axis

c-498

nomograph

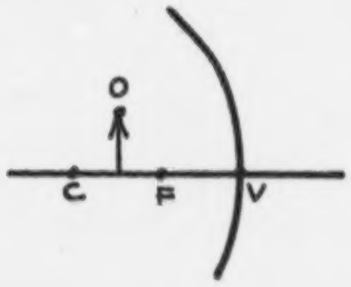
A·I·R ©1960

C-493

To find the image distance when the object distance and focal length are known, we can also use the formula $\frac{1}{f}$ = ☐.

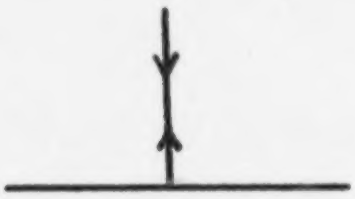
C-461

Locate and draw the image corresponding to this object.



C-429

Whenever an incident ray is perpendicular to a reflecting surface, the reflected ray will take the same ☐ as the incident ray took; that is, the reflected ray will not be reflected off at an angle. This is shown in the figure, with one arrow showing the direction of the incident ray and the other arrow showing the direction of the ☐.



C-397

In studying plane (or, flat) mirrors, you learned that an imaginary line drawn perpendicular to the surface (Figure 1) was called a ☐. In reflection from curved surfaces, it is also true that any line drawn perpendicular to the surface (Figure 2) is called a ☐.

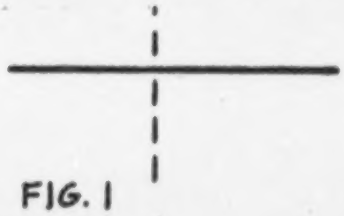


FIG. 1

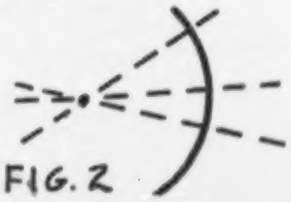
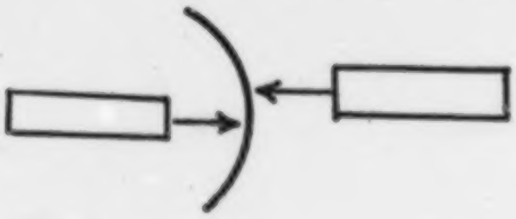


FIG. 2

A·I·R ©1960

C-371

Here is a drawing of a curved surface. Label the two sides, using the words "convex" and "concave."



C-403

The rays of light in Figure 1 are ________. The rays of light in Figure 2 are ________. The rays of light in Figure 3 are ________.

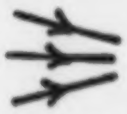


FIG. 1

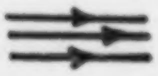


FIG. 2

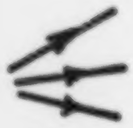


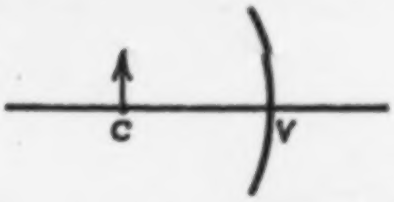
FIG. 3

C-435

An image point of a real image is where all the light rays striking a concave mirror ________. The image point of a virtual image is where all the light rays representing a given object point seem to be * ________.

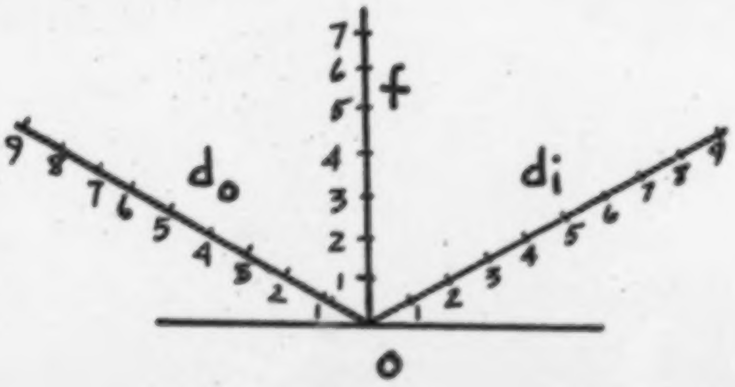
C-467

In this figure, the object is placed at point C. By locating and drawing the image, you can see it is a (real/virtual) ________ image, that it is (upright/inverted) ________, and that it is the same size as the ________.



C-499

This nomograph is the one which can be used to find either f or d_o or d_i when the other two are known. In this nomograph, one line represents object distance, a second represents * ________ and the third represents * ________.

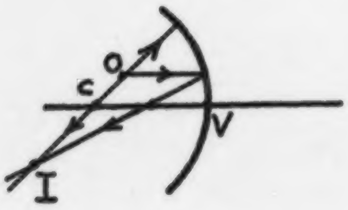


A·I·R ©1960

c-492

$\left(\frac{1}{f} = \frac{1}{3} + \frac{1}{2} = \frac{2}{6} + \frac{3}{6} = \frac{5}{6},\ f = \frac{6}{5} =\right)$ 1.2 (or, $1\frac{1}{5}$)

c-460



c-428

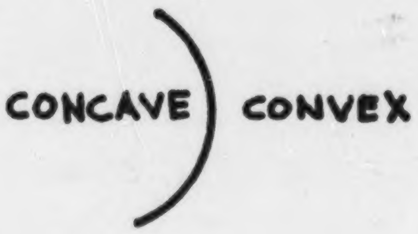
perpendicular
zero

c-396

principal axis (secondary axis)
secondary axis (principal axis)

A·I·R ©1960

c-371



c-403

converging
parallel
diverging

c-435

intersect (or, meet, cross, focus)
coming from

c-467

real
inverted
object

c-499

image distance (focal length)
focal length (image distance)

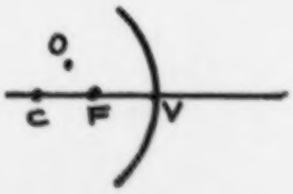
A·I·R ©1960

C-492

If d_o = 3 inches and d_i = 2 inches, f = # ______ inches.

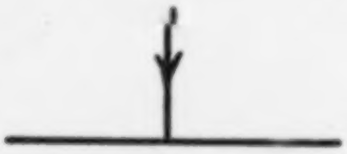
C-460

For this figure, locate the image point corresponding to object point O. Label it I.



C-428

In studying plane reflection, you learned that if a ray of incoming light had an angle of incidence of zero degrees, the ray would coincide with the normal; that is, it would be ______ to the surface. In this case, the angle of reflection would also be $ ______ degrees and the ray would be reflected back along the same path it took as it approached the surface.



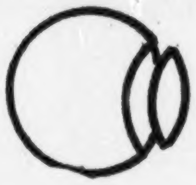
C-396

Any line drawn perpendicular to the surface of a spherical mirror must be a radius of curvature. In the terms that we have used in talking about spherical mirrors, it must also be either the * ______ or a * ______.

A·I·R ©1960

C-372

Many of the curved surfaces used in reflection are sections of a sphere (say, sfeer). We could make a spherical mirror by cutting a section off a hollow ball. If we coated the outside surface with a reflecting material, we would have a convex spherical mirror. If we coated the inside, we would have a * mirror.



C-404

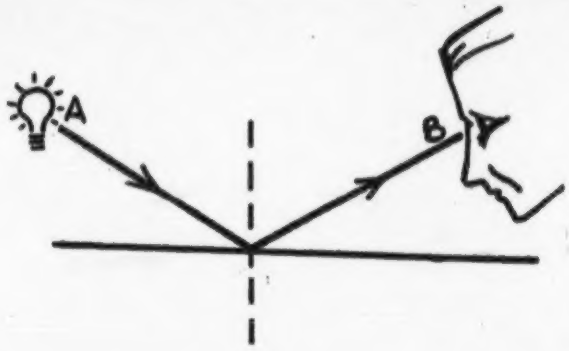
If we cut a section off a hollow metal ball or sphere, and coated the inside (or cave-like part) with a reflective material, we would have a ☐ spherical mirror. If, instead, we coated the outside with reflective material, we would have a * .

C-436

It is not necessary to draw all the rays of light from each object point that strike the curved mirror, since we know that ** at one point. We find this point with any two of the lines representing rays of light.

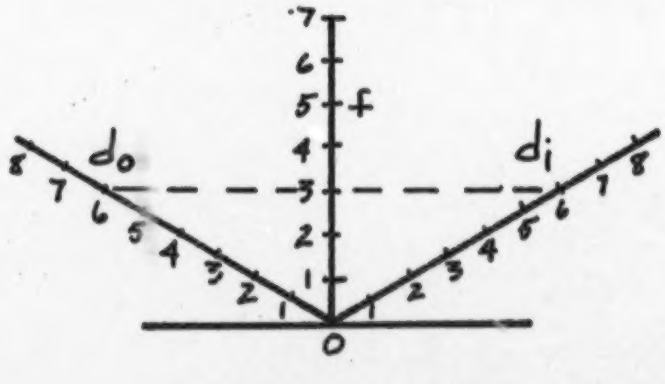
C-468

Light rays are reversible or retraceable; that is, if the source were moved to point B in the figure, we would see the image of the source by placing our eye at point $.



C-500

To use the nomograph, draw a straight line through the two values that are known. The point where this line crosses the scale representing the third value indicates what the third value is. The values indicated by the line that has been drawn in this figure are $d_o = 6$, $f =$ # , and $d_i =$ # .



A·I·R ©1960

END OF UNIT

c-491

$(\frac{1}{f} =)\ \frac{1}{d_o} + \frac{1}{d_i}$

$(\frac{1}{f} =)\ \frac{3}{6} = \frac{1}{2}$

$(f = \frac{6}{3} =)2$

c-459

principal axis
focal point
center of curvature

c-427

24
24

c-395

perpendicular
perpendicular

A·I·R ©1960

⑱③

c-372

concave spherical

---

c-404

concave
convex spherical mirror (surface)

---

c-436

they will all intersect (meet, converge, focus)

---

c-468

A

---

c-500

(f=) 3
(d_i =) 6

A·I·R ©1960

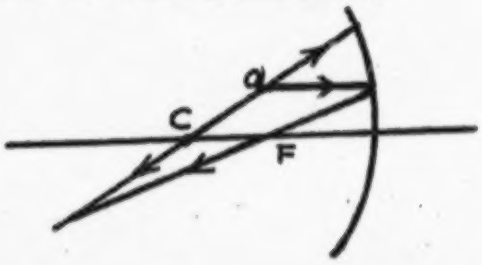
END OF UNIT

C-491

The formula for finding f, knowing d_o and d_i is $\frac{1}{f} =$ $. If d_o equals 6 inches and d_i equals 3 inches, $\frac{1}{f} = \frac{1}{6} + \frac{1}{3}$, or $\frac{1}{f} =$ # . To find f, we must invert the fraction and then divide the numerator by the denominator, or f = # inches.

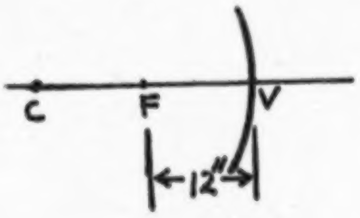
C-459

When the object point is between C and F, we can still locate the corresponding image point by using two rays of light. One begins parallel to the * , is reflected at the surface of the mirror, and passes through F, the * The other is a secondary axis. It passes through the * of the mirror.



C-427

If parallel rays of light come to a point at a distance of 12 inches from the vertex of a concave spherical mirror, we know the mirror has a radius of curvature of # inches; that is, the center of curvature is # inches from the vertex.



C-395

The principal axis of a spherical mirror is ☐ to the mirror's surface. Each secondary axis is also ☐ to the mirror's surface.

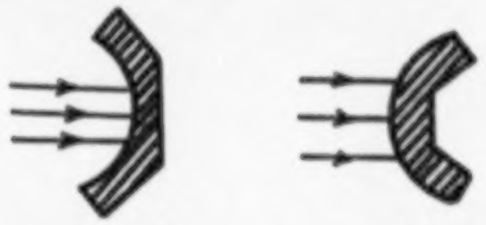
A·I·R ©1960

C-373

A sphere is a round object, like a ball. A spherical mirror is a mirror made in the shape of a section or piece of a ☐. If it is shiny on the inside, it is a ☐ spherical mirror. If it is shiny on the outside, it is a [*].

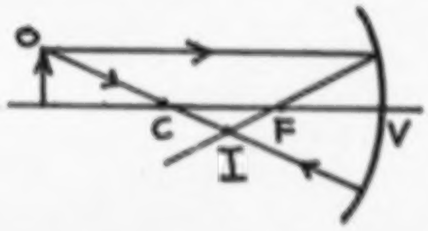
C-405

A concave mirror curves (inward/outward) ☐, but a convex mirror curves (inward/outward) ☐.



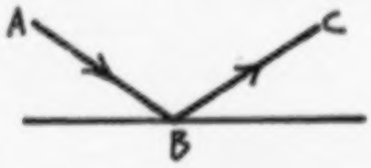
C-437

Generally, we locate the image formed by a curved mirror with two lines, a line drawn from an object point parallel to the principal axis, and a line drawn from the object point through the center of curvature to the surface; that is, a ☐ axis.



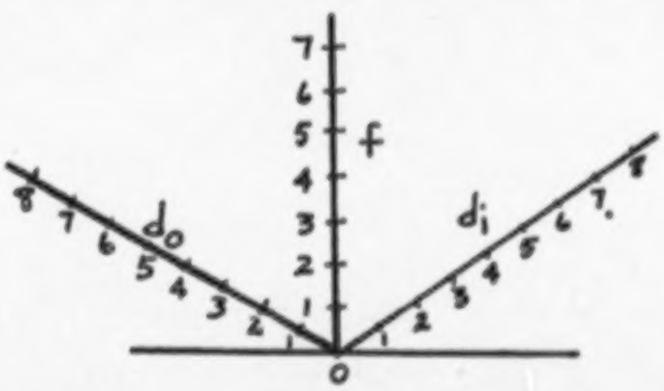
C-469

Since light rays are reversible or retraceable, by moving the source of light, in this figure, to the path of what is now the reflected ray, the ray of light BC would then be an incident ray, and the light that struck the surface at point B would be reflected out along line [$]. This is one way of demonstrating the ☐ of light.



C-501

Use this nomograph to find d_i when f is 2 and d_o is 6. Draw a straight line through these two values and to the scale for d_i; d_i = [#]. Then, find f when d_o is 5 and d_i is 5; f = [#].



A·I·R ©1960

c-522

concave

c-490

focal length
reciprocal of the object distance
reciprocal of the image distance

c-458

farther

c-426

focused (or, converged)
10

c-394

principal axis
secondary axis
perpendicular

A·I·R © 1960

187

c-373

sphere (this is better than saying ball or round object)
concave
convex spherical mirror

c-405

inward
outward

c-437

secondary

c-469

BA (or, AB)
reversibility (or, retraceability)

c-501

3
$\frac{5}{2}$ (or, 2.5, 2 $\frac{1}{2}$)

A·I·R ©1960

C-522

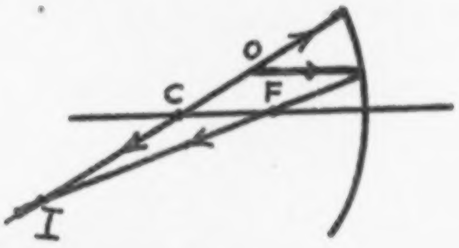
Later, when you study lenses, you will learn about telescopes. Some telescopes are made only of lenses, but some also use a large concave mirror. The mirror is used to focus the almost parallel rays of light coming from distant stars. These telescopes are called reflecting telescopes. A reflecting telescope, in addition to lenses, contains a large [ ] mirror.

C-490

We use reciprocals to find focal length when object distance and image distance are known, using the formula $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$. In words, this formula is that the reciprocal of the [*] equals the [*] plus the [*].

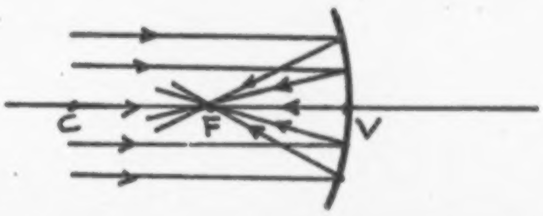
C-458

In some cases, light from a given object point may converge farther away from the mirror than the object. In this figure, image point I, corresponding to object point O, is (nearer/farther) [ ] from the mirror than the object point.



C-426

The radius of curvature for this spherical mirror is 20 inches. Parallel rays of light coming into the mirror will be [ ] at a point [#] inches from the vertex of the mirror.



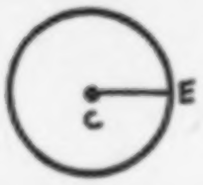
C-394

The principal axis and every secondary axis lie on top of some radius of curvature. Since a radius of curvature is always perpendicular to the surface of a spherical mirror, the [*] and every [*] must also be [ ] to the surface of the mirror.

A·I·R ©1960

C-374

A circle is shown in the figure. The center of the circle is labeled $ ______. The distance from the center of the circle to any point on its circumference (or edge) is called a radius. Line CE in the figure represents a ______.



C-406

The law of reflection is that the angle of ______ equals the * ______. This law is true for curved reflective surfaces as well as for plane surfaces. It is true for both inward curving, or ______ mirrors and outward curving, or ______ mirrors.

C-438

The two lines usually used to locate the image point corresponding to a given object point for a curved mirror are a line drawn ______ to the * ______ and a line drawn through the center of curvature; that is, a * ______.

C-470

Rays of light which are parallel to the principal axis of a spherical mirror will converge or focus at the * ______ (Figure 1). Since light rays are reversible, if we place the source at the focal point of a spherical mirror (Figure 2), the light rays reflected away from the mirror will be ______ to the principal axis.

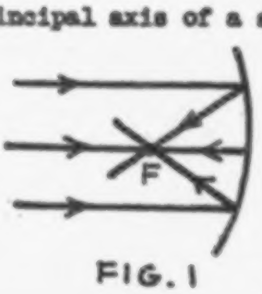


FIG. 1

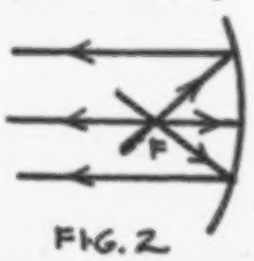


FIG. 2

C-502

You have learned how to locate the image formed by a concave spherical mirror when the object is farther from the vertex than the focal point; that is, when d_o is greater than $ ______. The images that you have found so far for spherical mirrors have all been (real/virtual) ______ images.

A·I·R ©1960

c-521

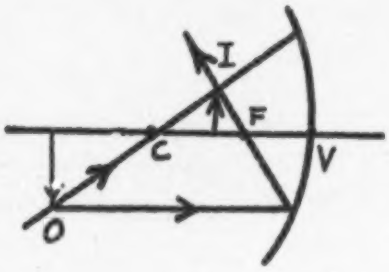
parabolic
parabolic

c-489

(M =) $\frac{12}{5}$

(M =) 2.4

c-457



c-425

f
radius
half way between (or, half the distance between)

c-393

perpendicular
perpendicular

A·I·R ©1960

⑲

c-374

C
radius

c-406

incidence (reflection)
angle of reflection (angle of incidence)
concave
convex

c-438

parallel
principal axis
secondary axis

c-470

focal point
parallel

c-502

f
real

A·I·R ©1960

C-521

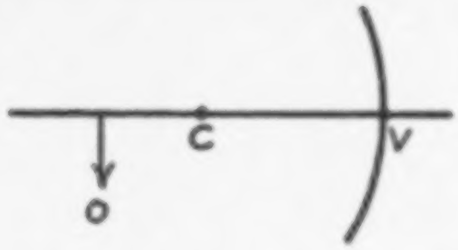
If we want to project parallel rays of light by placing a source at the focal point, we should use a ________ mirror rather than a spherical mirror. The reflective surfaces used in most automobile headlights, for instance, are ________ mirrors rather than spherical mirrors.

C-489

If $\frac{1}{k} = \frac{5}{10}$, then $k = \frac{10}{5}$, or $k = 2$. If $\frac{1}{M} = \frac{5}{12}$, then $M = \boxed{\#\quad}$, or $M = \boxed{\#\quad}$.

C-457

Locate the image for this figure and draw it in.



C-425

The focal length, or [$], is half as long as the ________ of curvature for a spherical mirror. The focal point, on the principal axis, is [*] ________ the center of curvature and the vertex.

C-393

A radius of a circle is always ________ to the circumference. A radius of curvature is also always ________ to the surface of the spherical section.

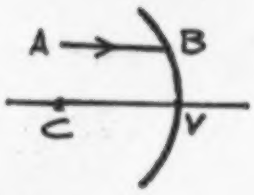
A·I·R ©1960

C-375

A radius of a circle is the distance from the ________ of the circle to any point on its ________. No matter where we measure a ________, its length for any one circle is always the same.

C-407

This figure shows a single ray of light (AB) drawn parallel to the * ________ of this spherical mirror. We would call the ray of light (an incident/a reflected) ________ ray.



C-439

A ray of light traveling toward the surface of a spherical mirror along a secondary axis arrives at the mirror ________ to the surface at that point. It coincides; that is, it lies on top of, a normal drawn at that point. Therefore, the angle of incidence is 0° and the angle of reflection is # ________ degrees.

C-471

If a light source is placed at the focal point of a concave spherical mirror, the light rays reflected by the mirror will all be ** ________. This is another demonstration of the ________ of light.

C-503

Not all images formed by a spherical mirror are real images. If the object is placed between F, the * ________, and V, the ________, a magnified, virtual image will be formed.

A·I·R ©1960

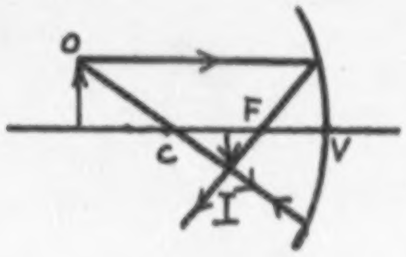
c-520

spherical
parabolic
spherical

c-488

10

c-456



c-424

half
C (V)
V (C)

c-392

radius

A·I·R ©1960

195

c-375

center
circumference (or, edge)
radius

c-407

principal axis
an incident

c-439

perpendicular
0 (zero)

c-471

parallel to the principal axis
reversibility

c-503

focal point
vertex

A·I·R ©1960

C-520

A parabolic mirror is shown in Figure 1 and a ☐ mirror is shown in Figure 2. The ☐ mirror will focus all incoming parallel rays of light at a single point, but a ☐ mirror will not.

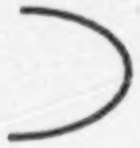


FIG. 1

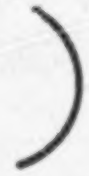


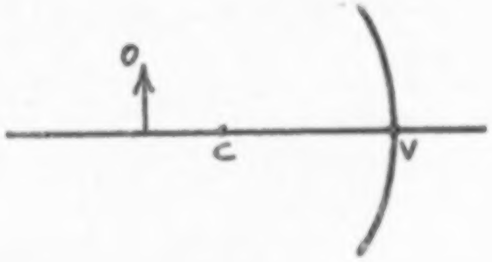
FIG. 2

C-488

Often when we do a problem involving the reciprocals of numbers, we must convert the answer back into a whole number. For instance, if $\frac{1}{A} = \frac{1}{7}$, then A = 7, and if $\frac{1}{R} = \frac{1}{10}$, then R = [#].

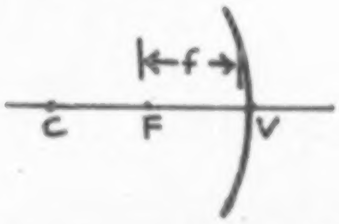
C-456

Locate the image for this figure and draw it in.



C-424

The symbol F stands for focal point. The symbol f stands for focal length. We know that the focal length is exactly ☐ the distance from point [$] to point [$].
In symbols, $f = \frac{1}{2}$ CV.



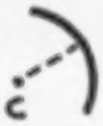
C-392

From geometry, we know that a line can be drawn perpendicular to a curved line. In a circle, any line drawn from the center of the circle to the circumference is perpendicular to the circumference. That is, any ☐ of the circle is perpendicular to the circumference.

A·I·R ©1960

C-376

We also speak of a center and a radius when we only have a portion of a circle. In this case, however, we call them the center of curvature and the radius of curvature. For a portion of a circle, the radius of curvature is the distance from the center of ________ to any point on that portion of a circle.



C-408

To draw the normal for an incident ray parallel to the principal axis of a curved mirror, we draw a dotted line ________ to the surface of the mirror at the point the ray touches.

C-440

A ray of light arriving at the surface of a curved mirror along a secondary or the principal axis will be reflected back ** ________ ________.

C-472

To obtain a beam of parallel light rays by using a concave spherical mirror, we place the source of light at the * ________ of the mirror. This point is located on the principal axis, half-way between the * ________ and the ________.

C-504

A virtual image point is where the rays of light ** ________.
Virtual images are always erect, or ________. They must be view with the eye and cannot be projected on to a screen.

A·I·R ©1960

c-519

parabolic

c-487

$(\frac{1}{2} - \frac{1}{3} =)\ \ \frac{3}{6} - \frac{2}{6}\ (=)\ \frac{1}{6}$

c-455

real image

c-423

focal point
center of curvature
vertex
curvature

c-391

center
radius

A·I·R ©1960

(199)

c-376

curvature

c-408

perpendicular

c-440

along the same path (as it had an incident ray)

c-472

focal point
center of curvature (vertex)
vertex (center of curvature)

c-504

seems to come from
upright (or, right side up)

A·I·R ©1960

C-519

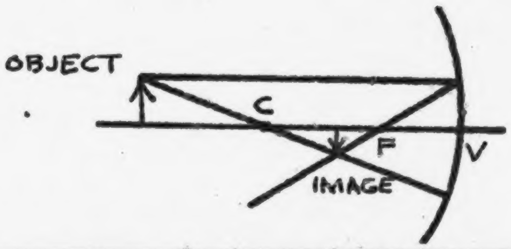
By using a mirror of a slightly different shape, all the incident rays which are parallel to the principal axis will focus at one point. We call these surfaces parabolas (say, par-ab-oh-las) or parabolic mirrors. A ______ mirror has a slightly different shape than a spherical mirror.

C-487

One reciprocal can be subtracted from another; $\frac{1}{2} - \frac{1}{4} = \frac{2}{4} - \frac{1}{4} = \frac{1}{4}$. In the same way, $\frac{1}{2} - \frac{1}{3} =$ # ______ = # ______.

C-455

In this figure, an image has been drawn corresponding to the object shown. As you can see from this figure, the image is inverted and is located where rays of light intersect, so it is a * ______.

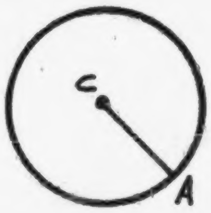


C-423

An interesting aspect of spherical mirrors is that F, the * ______, is exactly half way between C, the * ______, and V, the ______. Said another way, the focal length is exactly half the length of the radius of ______ for the spherical section.

C-391

A radius of a circle is any line drawn from the ______ of the circle to its circumference. Line CA in this figure is a ______ of the circle.



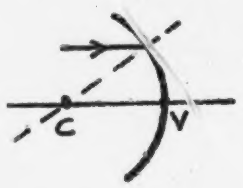
A·I·R ©1960

C-377

When we have a circle, we talk about the center and radius of that circle. When we talk about only a portion of a circle, however, we talk about the ______ of curvature and * ______ for that portion.

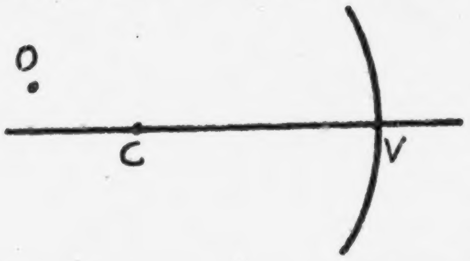
C-409

To draw a normal at the point an incident ray touches the surface of a spherical mirror, we draw a line from that point on the surface through the * ______ of the mirror. If the ray strikes the surface at the vertex, the normal would correspond to the * ______ . If the ray strikes anywhere else, the normal would be a * ______ .



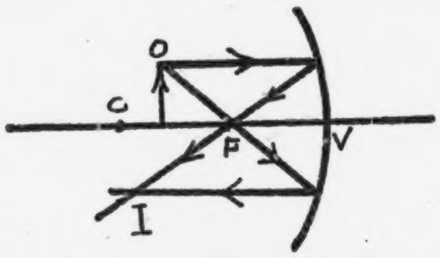
C-441

Draw a line parallel to the principal axis from object point O to the mirror's surface. Label the point on the surface where it strikes with a P. Then draw a second line from point O through the center of curvature to the mirror's surface; that is, a secondary axis. Label the point it strikes with an S. Show the direction of light with arrows.



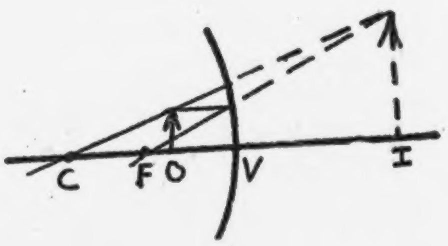
C-473

In this figure, the image point corresponding to object point O has been found by drawing a line through the focal point instead of through the * ______, and by another line parallel to the * ______. It does not make any difference which two lines we use, since ______ the rays of light leaving an object point and striking the mirror focus at a single * ______.



C-505

This figure shows how images are located for objects less than one f from the vertex. Notice that the image is behind the mirror, so it is (real/virtual) ______. Notice also that it is (erect/inverted) ______ and that it is (larger/smaller) ______ than the object.



A·I·R ©1960

c-518

defects in the way images are formed by spherical mirrors (if the mirror represents a large section of a sphere)

---

c-486

$(\frac{1}{2} + \frac{1}{3} = \frac{3}{6} + \frac{2}{6} =)\ \frac{5}{6}$

---

c-454

real
inverted
virtual
erect

---

c-422

vertex
focal length

---

c-390

center of curvature
vertex
center of curvature
vertex

A·I·R ©1960

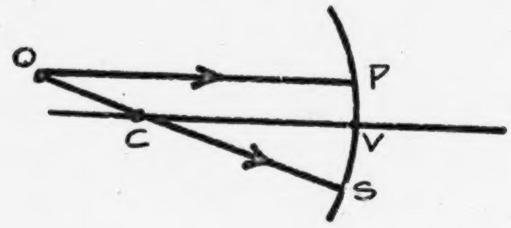
c-377

center (radius)
radius of curvature (center of curvature)

c-409

center of curvature
principal axis
secondary axis

c-441



c-473

center of curvature
principal axis
all
image point

c-505

virtual
erect
larger

A·I·R ©1960

C-518

Spherical aberrations are ** ______________________________ .

C-486

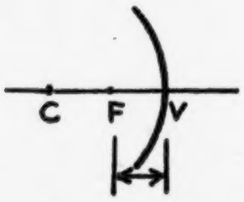
To add the reciprocals of two numbers, we first must convert the numbers to their reciprocals, then find the lowest * ______________ , and then add. The sum of the reciprocals of 2 and 3 = # ______ .

C-454

If an image is made of actual rays of light, we know it is a ______ image and that it will be (erect/inverted) ______ . If an image appears to be located where there are actually no rays of light, we know it is a ______ image and that it will be (erect/inverted) ______ .

C-422

The distance from the point where rays of light parallel to the principal axis are focused and the middle of the mirror,
or the ______ , is called
the * ______________ .



C-390

A principal axis is a line drawn through both the * ______________ and the ______ . A secondary axis is a line drawn through the * ______________ but not the ______ .

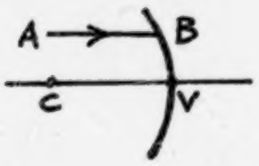
A·I·R ©1960

C-378

A sphere also has a center and a radius. The radius of a sphere is the distance from the ________ of the sphere to any ________ on its surface.

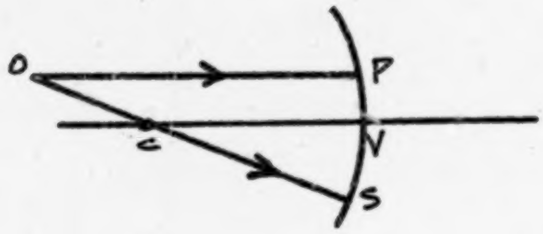
C-410

Ray AB is parallel to the principal axis of this spherical mirror. Draw a normal at the point it touches the surface using a dotted line.



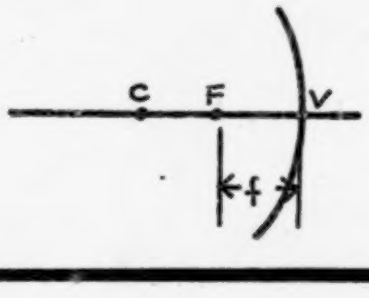
C-442

Now, draw a normal at point P, using a dotted line.



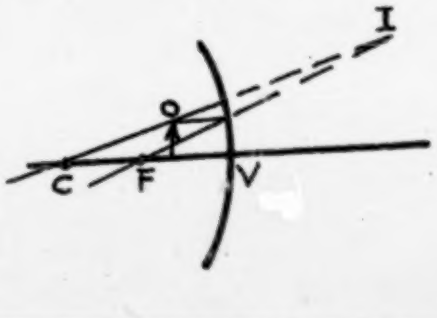
C-474

The focal length, or "f," of a spherical mirror is half the distance between the *________ ________ and the ________.



C-506

A virtual, erect, and magnified image is formed when an object is placed between the *________ and the vertex of a concave spherical mirror. Complete this figure by drawing the image.



A·I·R ©1960

c-517

spherical aberrations
spherical aberrations

---

c-485

$(\frac{1}{3}+\frac{1}{5}=)\ \frac{5}{15}+\frac{3}{15}=\frac{8}{15}$

---

c-453

real
virtual
upside down

---

c-421

focal length

---

c-389

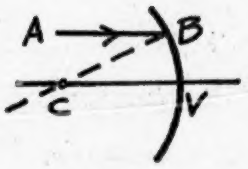
principal axis
secondary axis

A·I·R ©1960

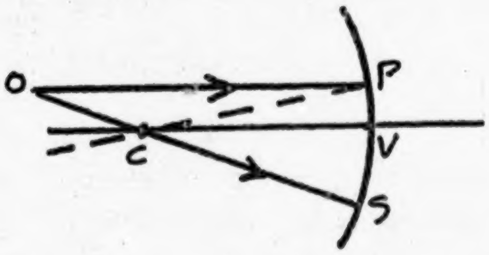
c-378

center
point (or, place)

c-410



c-442

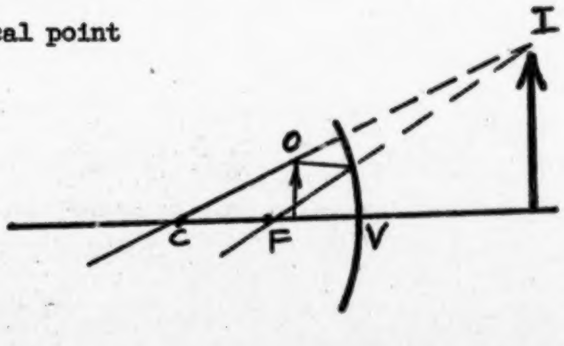


c-474

center of curvature (vertex)
vertex (center of curvature)

c-506

focal point



A·I·R ©1960

C-517

The defects in the formation of images by spherical mirrors are called * . If we use a mirror which represents only a small section of a sphere, these defects, or * are not very noticable.

C-485

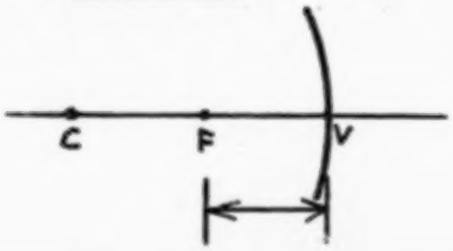
Now try this problem, $\frac{1}{3} + \frac{1}{5} =$ # .

C-453

A ☐ image can be projected on a screen, a ☐ image cannot. A real image is always inverted; that is, it is always * , but a virtual image is always erect or right side up.

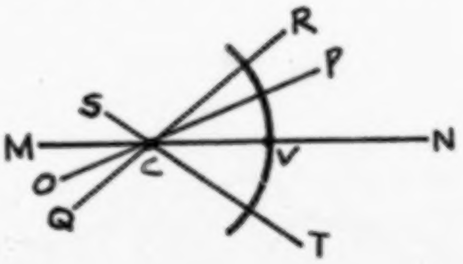
C-421

The distance from the focal point to the vertex is called the focal length. In this figure, the distance from F to V is the * for this mirror.



C-389

In this figure, line MN is the * . Lines OP, QR, and ST are each a * .



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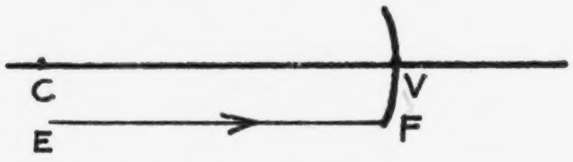
C-379

When we only have a section, or portion, of a sphere, we use the terms center of curvature and ______ of curvature, just as we did when we talked about a portion of a circle. A spherical mirror is a portion of a sphere. Therefore, to describe the shape of the mirror, we use the terms *______ and *______.

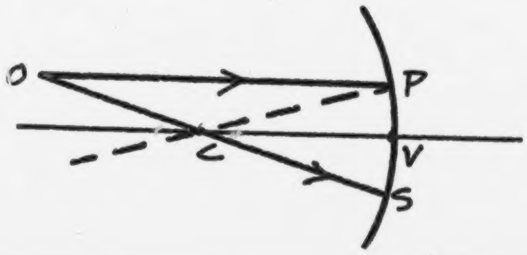
C-411

Ray EF is parallel to the principal axis of this spherical mirror. Draw a normal at the point it touches the surface using a dotted line.



C-443

Now, draw the reflected ray from point P. The point where this reflected ray crosses the principal axis is called the focal point. Label it F. Only if F is half-way between C and V are you sure that you made your drawing correctly; that is, with i = i'.



C-475

When an object is placed in front of a spherical mirror, we can measure the object distance; that is, the distance from the object to the vertex of the mirror, measured along the principal axis. The focal length of a mirror is the distance from the *______ to the vertex, and the *______ is the distance from the object to the vertex.

C-507

As you have learned, there are two kinds of spherical mirrors. Figure 1 illustrates a ______ mirror and figure 2 illustrates a ______ mirror.

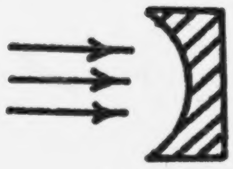


FIG. 1

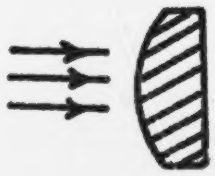


FIG. 2

A·I·R ©1960

c-516

spherical aberrations
large

c-484

$(\frac{1}{5} + \frac{1}{4} =) \frac{4}{20} + \frac{5}{20} = \frac{9}{20}$

c-452

real
can

c-420

focal point
principal axis

c-388

principal axis
secondary axis

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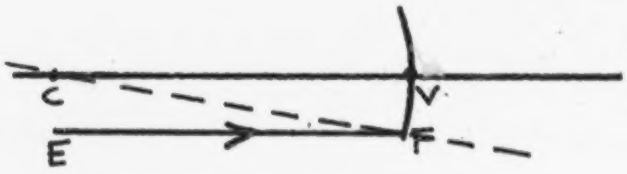
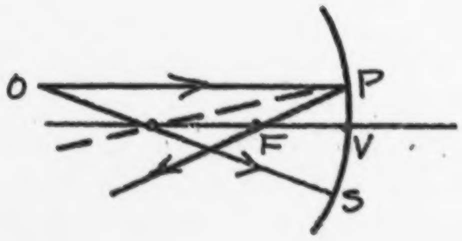
c-379

radius
center of curvature (radius of curvature)
radius of curvature (center of curvature)

c-411



c-443



c-475

focal point
object distance

c-507

concave
convex

A·I·R ©1960

C-516

The defect in the way spherical mirrors focus incident rays are parallel to the principal axis is called a spherical aberration. These defects, in the way spherical mirrors reflect light, or * ______________, only become important when the mirror represents a (large/small) ______ section of a sphere.

C-484

Try this problem, $\frac{1}{5} + \frac{1}{4} =$ # ______.

C-452

A real image is formed where there are actual rays of light. Real images can therefore be projected on to a screen. A virtual image can be seen by the eye, but it cannot be focused on a screen. If the image is formed by actual rays of light, we know it is a ______ image, and it (can/cannot) ______ be projected on a screen.

C-420

F, the * ______________ as well as the center of curvature and the vertex is located along a line called the * ______________ of a spherical mirror.

C-388

A secondary axis is a line drawn through the center of curvature of a spherical mirror to any point on the mirror except the vertex. You have already learned that a line drawn from the center of curvature through the vertex is called the * ______________. Any other line drawn through the center of curvature to the mirror's surface is called a * ______________.

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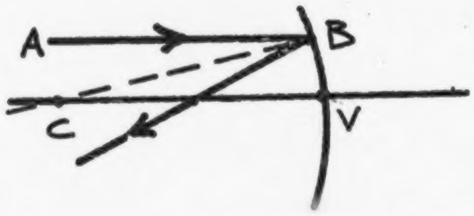
C-380

Every spherical mirror, whether it is convex or ______ has a center of ______ and a *______. It also has a vertex. The vertex of a section of a sphere is the middle of that piece of a sphere's surface. If we drilled a hole through the middle of a saucer, the hole would be at the ______ of the saucer.

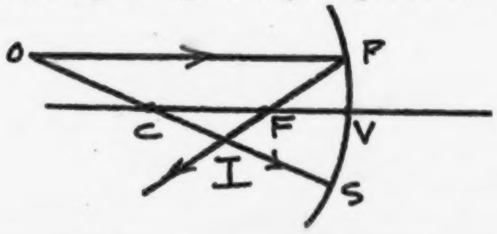
C-412

In this figure, ray AB is parallel to the principal axis. Since it is the ray coming toward the surface, it is the ______ ray.
A normal and a reflected ray have also been drawn.
Label the angle of incidence with the letter "i"
and the angle of reflection with the symbol "i'".
According to the law of reflection, i = $______.



C-444

The point where the reflected ray leaving point P and the reflected ray leaving point S intersect has been labeled I. It is the *______ corresponding to object point O.

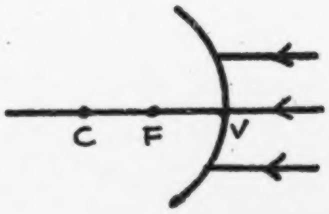


C-476

The image distance for a spherical mirror is the distance from the image to the vertex, measured along the *______. The distance from the focal point to the vertex is called the *______. The distance from the image to the vertex is the *______.

C-508

Using two lines to find each image point, we can also see how images are formed when objects are placed before a convex mirror. As shown in the figure, the center of curvature and focal point are both on the (same/opposite) ______ side as the shiny surface.



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c-515

focused (or, converged)

c-483

6

$\frac{3}{6} + \frac{1}{6}$

c-451

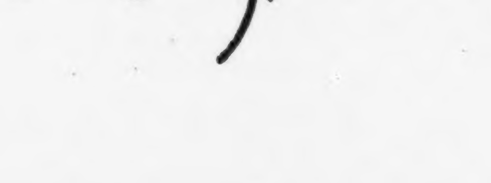
behind

virtual

c-419

incoming rays of light which are parallel to the principal axis are focused (converge)

c-387



A·I·R ©1960

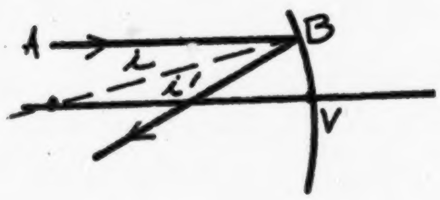
c-380

concave
curvature
radius of curvature
vertex

---

c-412

incident
(i =) i'



---

c-444

image point

---

c-476

principal axis
focal length
image distance

---

c-508

opposite

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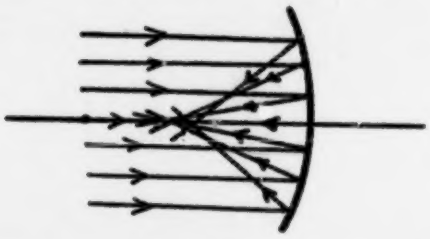
C-515

This figure shows how rays of light which are parallel to the principal axis are reflected by a spherical mirror. The rays which strike the mirror near its edges are not reflected in such a way that all the rays striking the mirror are ______ at one point.



C-483

To add $\frac{1}{2} + \frac{1}{3}$, we first have to change the problem so that both parts have the same denominator. Since the lowest common denominator is # ______, we write the problem as $\frac{3}{6} + \frac{2}{6}$. To add $\frac{1}{2} + \frac{1}{6}$, we would write the problem as $ ______

C-451

A real image point is formed where the rays of light from a corresponding object point intersect. A virtual image point is where the rays of light appear to be coming from. The image seen in a plane mirror seems to be located ______ the mirror. Since the rays of light obviously are not actually there, we know the image in a plane mirror must be a ______ image.

C-419

The focal point of a spherical mirror is where ** ______.

C-387

Draw a diagram of a spherical mirror. Draw a principal axis and label one end S and the other end T. Place a dot at the approximate center of curvature and label it C. Place a dot at the vertex and label it V.

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C-381

Figure 1 shows a section of a sphere. Figure 2 is a diagram of the same spherical section. It represents what the portion of a sphere would look like if we had only a thin slice of it. In either figure, point C represents the * ______, line CL represents a * ______, and point V represents the ______.

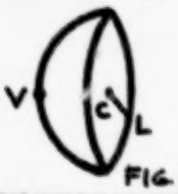


FIG. 1

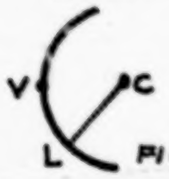
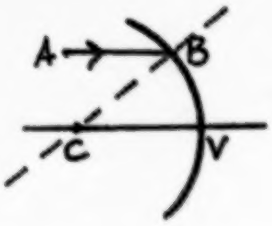


FIG. 2

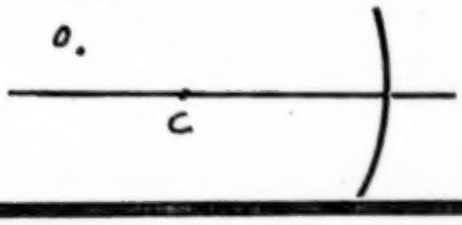
C-413

In this figure, ray AB is parallel to the principal axis. A normal has been drawn. Draw the reflected ray. Remember, i must equal i'.



C-445

Draw an incident ray parallel to the principal axis from object point O to the surface of the mirror. Use a dotted line to draw a normal at the point where the incident ray strikes the surface. Then draw a reflected ray from that point. Label points V and F.

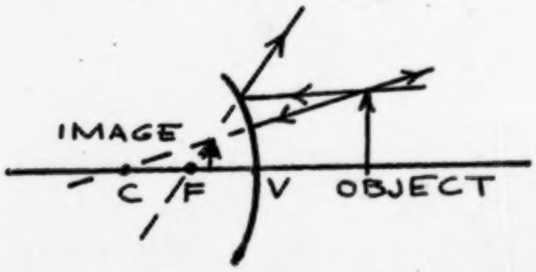


C-477

The image distance is the distance from the ** ______, measured along the * ______. The object distance, which is also measured along the * ______, is the distance from the ** ______.

C-509

This figure shows an object placed before a convex mirror, and the location of the image that will be seen. Since the image is behind the mirror, we know it must be a (real/virtual) ______ image.



A·I·R ©1960

c-514

large
smaller

c-482

4

c-450

principal axis

c-418

parallel
principal
focused (or, converged)

c-386

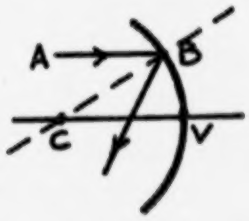
vertex
principal axis

A·I·R ©1960

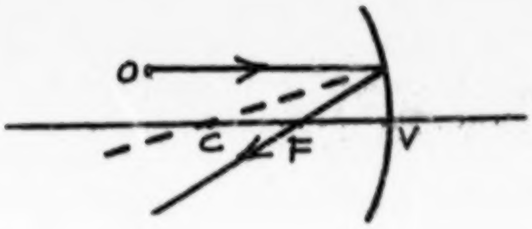
c-381

center of curvature
radius of curvature
vertex

c-413



c-445



c-477

image (vertex) to the vertex (image)
principal axis
principal axis
object (vertex) to the vertex (object)

c-509

virtual

A·I·R ©1960

C-514

The curved mirror shown in Figure 1 represents a (large/small) ☐ section of a sphere, while the one shown in Figure 2 represents a (larger/smaller) ☐ section.

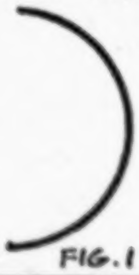


FIG. 1

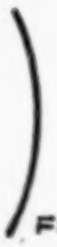


FIG. 2

C-482

We add or subtract the reciprocals of numbers just like we add or subtract fractions, by using the lowest common denominator. The lowest common denominator for $\frac{1}{3}$ and $\frac{1}{6}$ is 6. For $\frac{1}{2}$ and $\frac{1}{5}$ it is 10, and for $\frac{1}{4}$ and $\frac{1}{2}$ it is ☐ #.

C-450

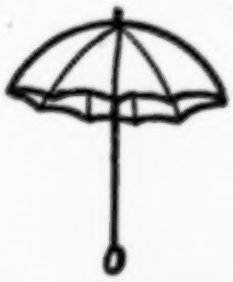
The image point corresponding to an object point which is on the principal axis will also be somewhere on the ☐ *.

C-418

When we speak of rays of light converging at a point, we usually say they are focused at that point. In a spherical mirror, the focal point is the point where incoming rays of light which are ☐ to the ☐ axis are ☐.

C-386

An open umbrella is much like a spherical section! The tip of the umbrella is at the ☐ of the umbrella, and the handle represents the ☐ * of the umbrella



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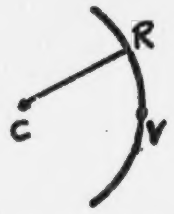
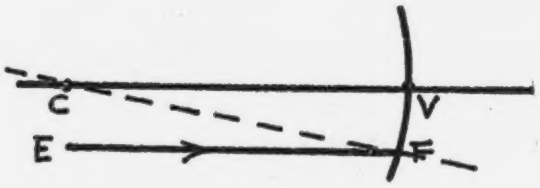
C-382

In this figure, point C is the * . ____ and point V is the ____ . Line CR is a * ____ .



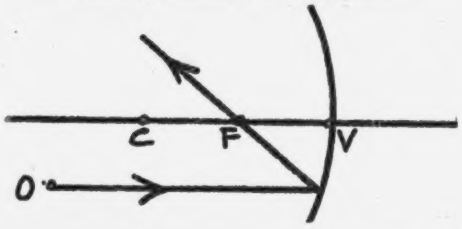
C-414

In this figure, ray EF is parallel to the principal axis. A normal has been drawn. Draw the reflected ray. Label angles i and i'.



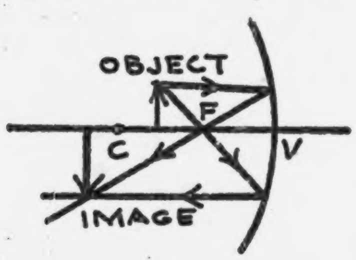
C-446

In this figure, the reflected ray for an incident ray parallel to the principal axis has been drawn. Add a secondary axis from point O. Label the image point corresponding to object point O with the symbol I.



C-478

We abbreviate image distance as d_i (say, dee-sub-eye), object distance as d_o (say, dee-sub-oh), and focal length as f. In this figure, f is less than either $ ____ or $ ____ .



C-510

Figure 1 shows the formation of a virtual image by a ____ mirror and figure 2 shows the formation of a virtual image by a ____ mirror.

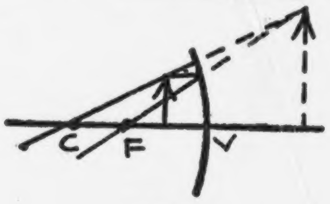


FIG. 1

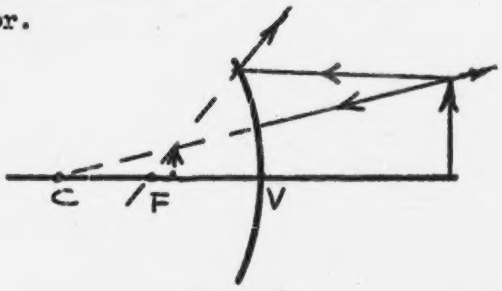


FIG. 2

A·I·R ©1960

c-513

focal point

c-481

$\frac{1}{f}$

c-449

principal axis (or, reflected ray)

c-417

focal point
center of curvature
vertex

c-385

center of curvature
vertex
principal axis

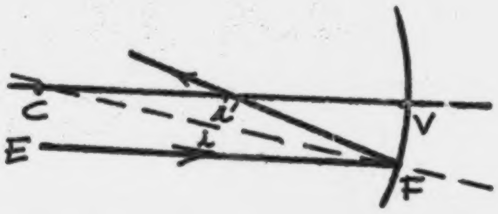
A·I·R ©1960

c-382

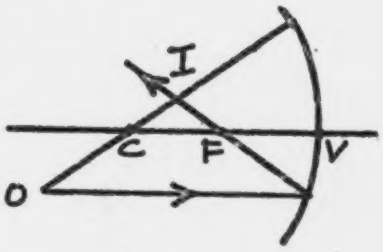
center of curvature
vertex
radius of curvature

c-414

(i must equal i' for the figure to be correct)



c-446



c-478

d_i (or) d_o

c-510

concave
convex

A·I·R ©1960

C-513

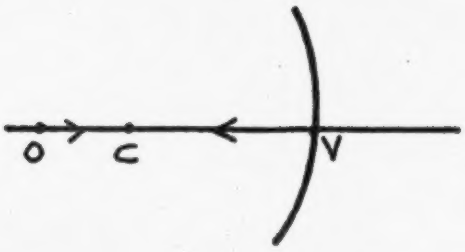
If a spherical mirror is too large, that is, if it represents too great a portion of a sphere, it will not focus all the rays of light which are parallel to the principal axis at one point. A mirror made from a small section of a sphere, however, will focus all these rays at the [*].

C-481

To calculate the image distance, we need to use the reciprocals of d_o and f. The reciprocal of a number is the fraction made by putting a "1" over that number. The reciprocal of d_o is $\frac{1}{d_o}$; the reciprocal of f is [$].

C-449

This figure shows the object point on the principal axis. We know that light leaving the object along the path of the principal axis will be reflected back along the same path; that is, the image point corresponding to this object point must lie somewhere along the [*].

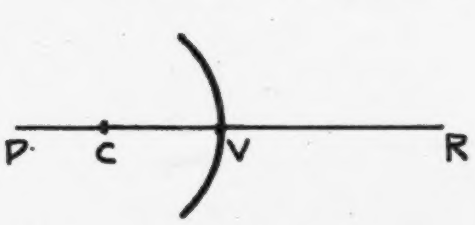


C-417

In diagrams of a spherical mirror, F stands for [*], C stands for [*], and V stands for [ ].

C-385

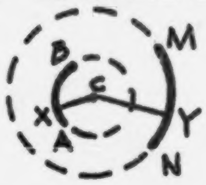
In this figure, the line PR which has been drawn through point C, the [*], and point V, the [ ], of this spherical mirror is called the [*].



A·I·R ©1960

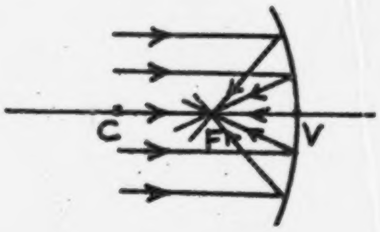
C-383

This figure shows two spherical surfaces, AB and MN. Both have the same *______________, labeled C, but since line CX is shorter than line CY, we know that the radius of curvature is shorter for spherical surface $______ than for $______. Surface AB is (more/less) ______ sharply curved than surface MN.



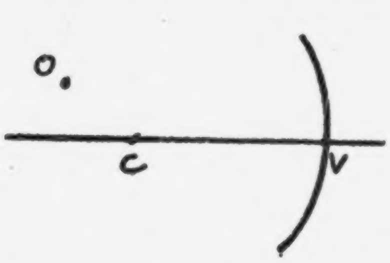
C-415

This figure shows that the reflected rays corresponding to incident rays which are parallel to the principal axis of a concave mirror will all tend to come together, or ______, at a point. This point is called the focal point. The symbol F in the figure stands for the *______ for this mirror.



C-447

For this figure, locate the image point corresponding to object point O. Label the point I.



C-479

The symbol d_1 stands for *______, the symbol $______ stands for object distance, and the symbol f stands for *______.

C-511

Concave mirrors can produce either real or ______ images depending on where the object is placed. If the object is more than 1 f away from the vertex, the image will be (real/virtual) ______. If it is less than 1 f from the vertex, the image will be (real/virtual) ______.

A·I·R ©1960

c-512

virtual

erect

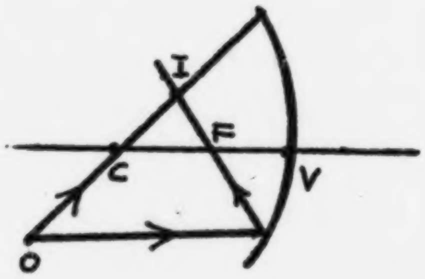
c-480

image distance

d_o

f

c-448



c-416

focal point

F

c-384

principal axis

A·I·R ©1960

c-383

center of curvature

AB

MN

more

---

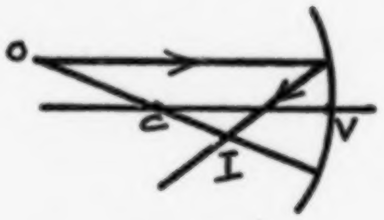
c-415

converge

focal point

---

c-447



---

c-479

image distance

d_o

focal length

---

c-511

virtual

real

virtual

A·I·R ©1960

C-512

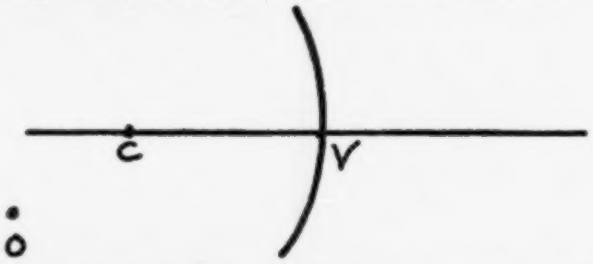
Convex mirrors always produce images behind the mirror, that is, [ ] images. They are always smaller than the object and are always (erect/inverted) [ ].

C-480

If we know the lengths of d_o and f, we can calculate the exact length of d_i. To calculate d_i; that is, the [*], we must know the object distance, or [$] and the focal length or [$].

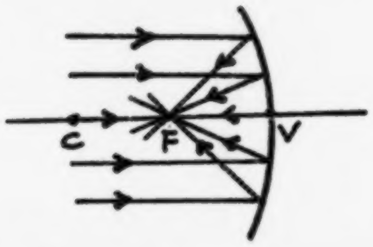
C-448

For this figure, locate the image point corresponding to object point o. Label the point I.



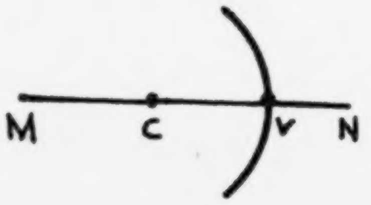
C-416

The point where parallel rays of light striking a concave mirror will converge is called the [*]. In the figure, this point is identified with the symbol [$].



C-384

The principal axis of a spherical mirror is a line drawn through both the center of curvature and the vertex. In this figure, line MN is the [*] of this mirror.



A·I·R ©1960

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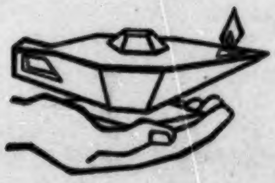
UNIT FIVE

POLARIZATION, DIFFRACTION AND AND INTERFERENCE

Steps C-523 through C-667



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UNIT ENDS HERE

C-523

In geometric optics, you learned that light rays have rectilinear propagation; that is, they travel in [*]. They will pass through a transparent object but not through an opaque [ ].

C-553

When we say that light has a wave motion, we mean that the path of each ray of light is in the form of a wave. For most purposes, we use a [ ] line, as in Figure 1, to illustrate the path of a single ray of light. When we talk about diffraction, however, we use a [ ] line, as in Figure 2.

FIG 1

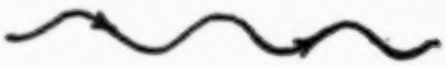


FIG. 2

C-583

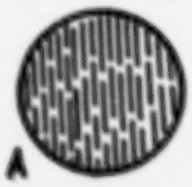
The effect that occurs when two waves come together is called interference. If the waves are in phase, constructive interference results. If the waves are not in phase, destructive [ ] results. If the combined wave is stronger than either original wave, we know [*] has occurred. If it is weaker, then [*] must have occurred.

C-613

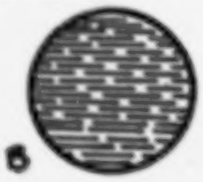
Since the separation of light bands depends on the λ of the light used, the light bands will be differently spread depending on the color of light used. The longer the wave length, the (wider/narrower) [ ] the bands will be spaced.

C-643

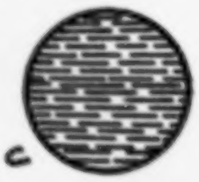
Suppose A, B, C represent three pieces of polaroid, with their crystals oriented as shown. If A and B were placed together, light (would/would not) [ ] get through. If B and C were placed together, light (would/would not) [ ] get through.



A



B



C

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c-642

polaroid

c-612

wave length
wave length
red light
closer together

c-582

troughs
weaker

c-552

wavelets (or, waves)
straight line

A·I·R ©1960

235

c-523

straight lines
object

c-553

straight
wavy

c-583

interference
constructive interference
destructive interference

c-613

wider

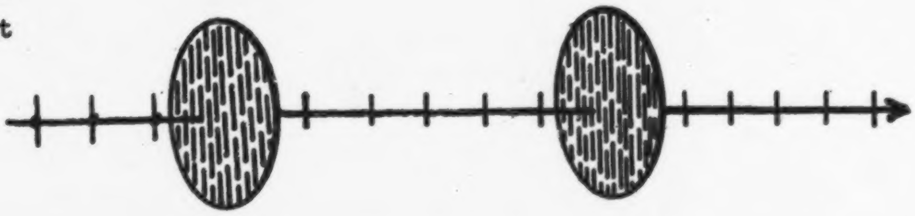
c-643

would not
would

A·I·R ©1960

C-642

If light which is polarized in a vertical plane by one polaroid screen then strikes a piece of polaroid that also has vertical crystals, the vertically polarized light will pass through the second piece of ☐.

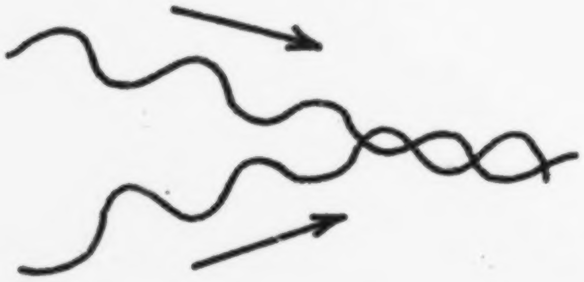


C-612

The λ, or ☐ *, for red light is about .000066 centimeters and for blue light is about .000046 centimeters. This is about 50,000 complete waves to the inch. Since blue light has a slightly shorter ☐ * than red light, the bands produced by blue light will be slightly closer together than the bands produced by ☐ *. The shorter the wave length, the (closer together/farther apart) ☐ the diffraction bands.

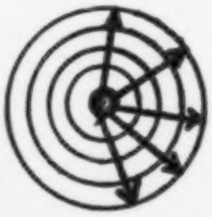
C-582

If two waves come together out of phase, then the crests of one line up with the ☐ of the other, and the combined wave will be ☐ than either of the two original waves.



C-552

As waves of light travel out in all directions from a point source, we could think of them as being made up of a large number of little ☐. Yet, although light has a wave motion, the over-all path of each ray of light can still be thought of as a ☐ *.



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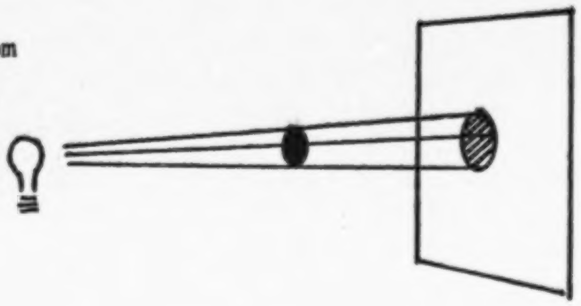
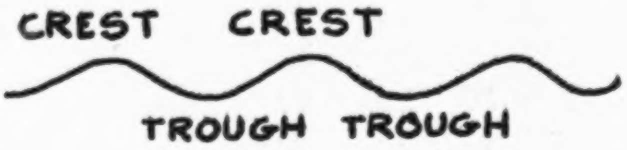
C-524

Since light travels in ☐ * from a small distant source, some of the light rays may strike an opaque object and only some of the light rays will go on past the edge of the object. A ☐ will be formed behind the object where the light does not fall.



C-554

In this diagram of a wave, we see the high points and low points of the wave. As shown in the figure, the high point of each wave is called a ☐ and the low point is called a ☐.



C-584

When waves come together in phase (Figure 1), ☐ interference results, and the combined wave (Figure 2) will be ☐ than either original wave.

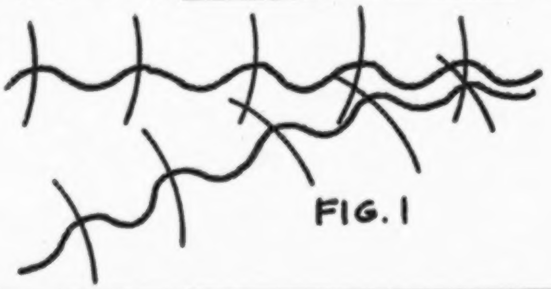


FIG. 1

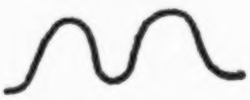


FIG. 2

C-614

Light with a long ☐ * such as red will form bands that are ☐ * than light with a shorter ☐ $, such as ☐.

C-644

If two polaroids are crossed at right angles; that is, perpendicular or opposite to each other, (Figure 1), the overlapping pieces will transmit ☐ * at all. If they are partially crossed (not at right angles) as in Figure 2, some ☐ will come through but it will not be very ☐.

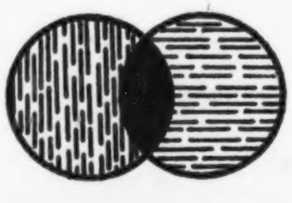


FIG. 1

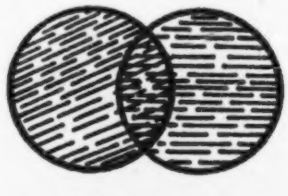


FIG. 2

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c-641

plane-polarized
absorbed (or, stopped, blocked)

c-611

x
D
d
λ

c-581

phase (or, step)
crests

c-551

waves
directions
(point) source of light
diffraction

A·I·R ©1960

c-524

straight lines (or, rectilinear propagation)
shadow

c-554

crest
trough

c-584

constructive
stronger

c-614

wave length
farther apart (or, wider spread)
λ
blue

c-644

no light
light
bright

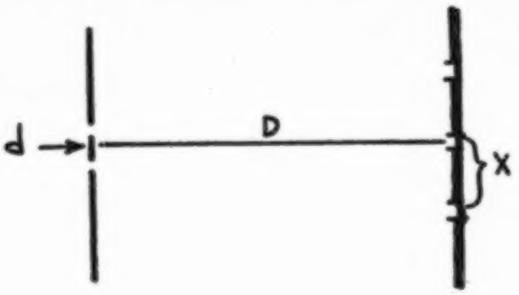
A·I·R ©1960

C-641

If we first plane-polarize the vertical wave motion of light, and then place a piece of horizontally oriented polaroid in the path of this vertically [*] light, all of the light will be [ ].

C-611

Wave lengths of light are very short (only a few hundred thousandths of a centimeter). We usually make two slits very close together but place the screen some distance away. Hence, both the distance from the barrier to the screen, or [$], and the distance between two adjacent bands, or [$], are much larger than either the distance between slits, [$] or the wave length, [$].

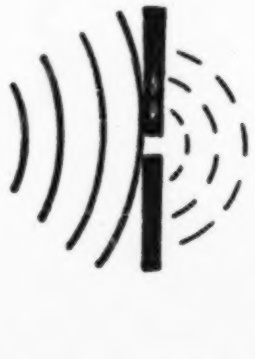


C-581

Two waves will produce a stronger wave if they are in [ ] when they come together; that is, if the crests of the first wave line up with the [ ] of the second wave.

C-551

If waves strike a slit in a barrier, new circles of [ ] spread out in all [ ] on the other side of the slit. This is because the slit serves as a new [*]. This spreading out of light is called [ ].



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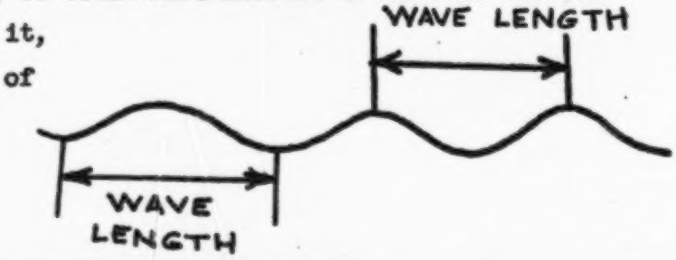
C-525

Black, well-defined shadows are formed only when the light comes from a point source; that is, one which is quite ______. If an extended, or ______ source is used, the shadow (will/will not) ______ be clear and distinct.

C-555

The distance between two crests of a wave is called the wave length. Although we generally measure wave length between two crests, we could also measure it between two low points, or ______. Whichever way we do it, the * ______ for any particular ray of light is the same wherever it is measured.



C-585

When two waves which are out of phase meet (Figure 1), they cancel out or destroy each other and the combined wave (Figure 2) is ______ than either original wave. This is called * ______.

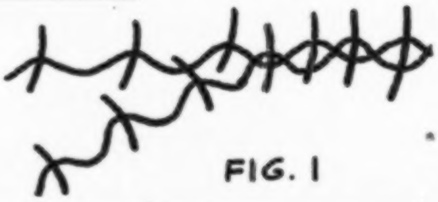


FIG. 1

FIG. 2

C-615

If we use more than two slits in the barrier, we will not change the spacing of the diffraction ______ as long as the same color light is used and the slits are the same width apart. The bright bands are produced because of interference, not because of light traveling directly through a ______.

C-645

We can tell in what direction, or ______, light has been polarized by one piece of polaroid, if we then test it with a second polaroid plate called an analyzer. When no light passes through the second piece, we know the light was plane-polarized in a direction which was ______ to the position of the crystals in the second piece.

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c-640

vertical wave motion (or, vibrations)
absorb (or, block) the horizontal wave motion (vibrations)

c-610

$(\lambda =)\ \frac{dx}{D}$ (or, $d\frac{x}{D}$)

c-580

in phase

c-550

set
pinhole (or, slit) at B
does
pinhole (or,hole)

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(243)

c-525

small
large
will not

c-555

troughs
wave length

c-585

weaker
destructive interference

c-615

bands
slit

c-645

plane
perpendicular (or, at right angles, opposite)

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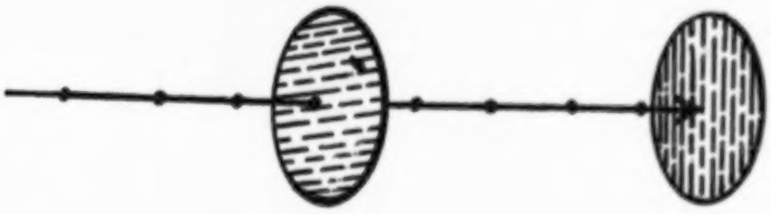
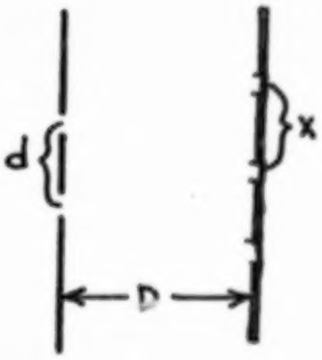
C-640

If we turn one sheet of polaroid so that its crystals are horizontal and a second piece with its crystals vertical, the first piece will absorb the * ____ ____ and the second piece will ** ____ ____. Thus, no light at all will get past the second piece.



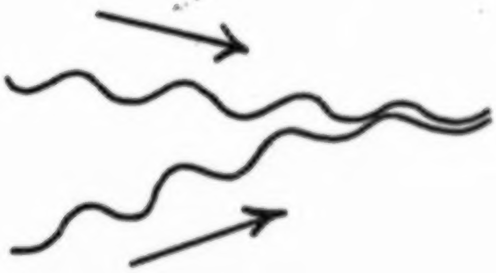
C-610

Another way to determine wave length is to use the formula, wave length equals d, the distance between slits, times x, the distance between the midpoint and the next bright band, divided by D, the distance between the barrier and the screen. In symbols, the formula is, $\lambda =$ $ ____.



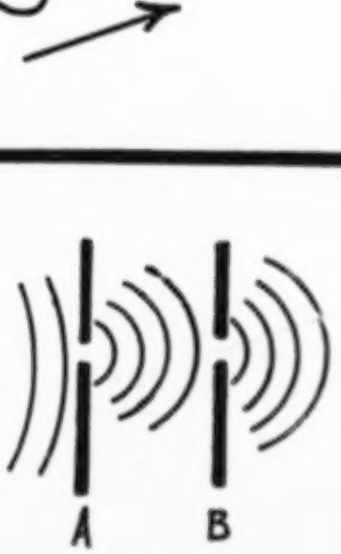
C-580

The two waves coming together in this figure have their crests lined up. They are * ____ and the combined wave will be stronger than either of the two original waves.



C-550

We cannot see the wavelets, but we can demonstrate that light travels in waves, and that any point on a wave can be thought of as a new ____ of wavelets. In this figure, the pinhole at A serves as a point source of light, and so does the * ____. Thus, light (does/does not) ____ spread out as it passes through a narrow slit or ____.



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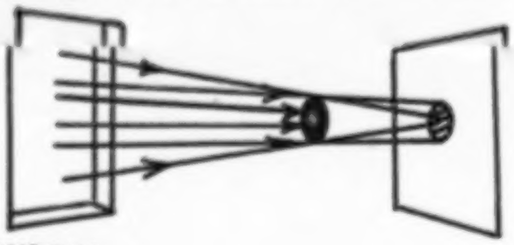
C-526

Part of the light comes in at an angle from the outer edges of an extended source, like a window. Thus, only part of the light is blocked by an ☐ object, and since some light will strike all parts of the screen, the shadow will appear (lighter/darker) ☐ than if a point source were used.



C-556

We use the Greek letter λ (say, lamb-da) to represent wave length. 1 λ equals one wave length, 2 λ equals ☐# wave lengths, 3 ☐$ equals ☐*, and so on.

C-586

When two waves which were in phase come together, ☐* would be produced. The combined wave will be ☐ than either of the original waves. If the combined wave falls on a screen, it will appear brighter than if either original wave fell on the screen.

C-616

By using many evenly spaced slits or lines ruled very close together on a piece of glass, we will not change the spacing or number of the diffraction bands but, since more light is admitted, each band will be (brighter/less bright) ☐ than with light from just two slits. In this case, the combined wave will be quite ☐ because it is produced where a large number of ☐ meet in ☐.

C-646

To the eye, light that is vibrating in only one plane; that is, ☐* light, looks just the same as ordinary light. We can test light to see if it is polarized, however, with a piece of polaroid material used as an analyzer. If the light is polarized, by rotating the ☐, we will alternately observe light passing through it and not passing through it.

A·I·R ©1960

c-639

horizontal (vertical) wave motion (vibrations)
vertical (horizontal) wave motion (vibrations)
absorbed (or, stopped, blocked)

c-609

one wave length
A
wave length
SA

c-579

in phase (or, in step)

c-549

wavelets

A·I·R ©1960

(247)

c-526

opaque
lighter

---

c-556

2
λ
three wave lengths

---

c-586

constructive interference
stronger

---

c-616

brighter
strong (or, bright)
waves
phase (or, step)

---

c-646

plane-polarized
analyzer

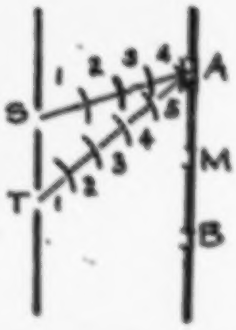
A·I·R ©1960

C-639

Depending on how it is turned, we can use a sheet of polaroid to eliminate either the [*] or the [*] of light. Polarization of light by using polaroid is called polarization by selective absorption, since only one kind of wave motion is transmitted while the others are selectively [ ].

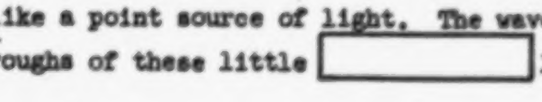
C-609

If A is the first bright band after M, the midpoint band, then we know the distance from slit T to A is exactly [*] greater than the distance from slit S to [$]. In formula form, λ, or [*] equals the distance TA minus the distance [$], or, $\lambda = TA - SA$.

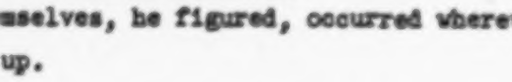


C-579

When the crests of one wave exactly line up with the crests of another, we way the two waves are in step, or in phase. If the crests of one line up with the troughs of the other, we say the two waves are not [*].



IN PHASE



NOT IN PHASE

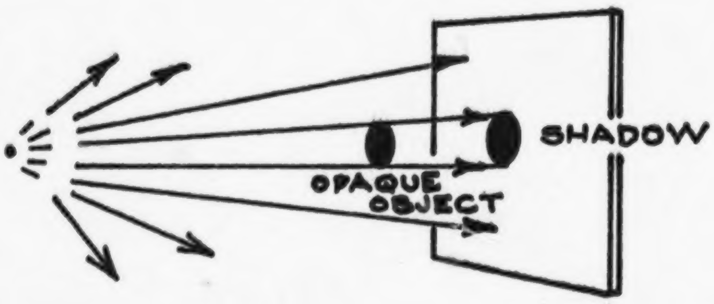
C-549

Huygens also said that each wave was actually made up of little wavelets, as if each point on a wave acted like a point source of light. The waves themselves, he figured, occurred wherever the crests and troughs of these little [ ] lined up.

A·I·R ©1960

C-527

If we have a point source of light, it will send out light rays in all ______, but none of these will strike the ______ behind the opaque object, and so the ______ will look black and seem to have sharp edges.



C-557

The wave length of a particular ray of light is the distance between two adjacent ______ or between two adjacent ______. Wave length is abbreviated by the symbol $ ______.

C-587

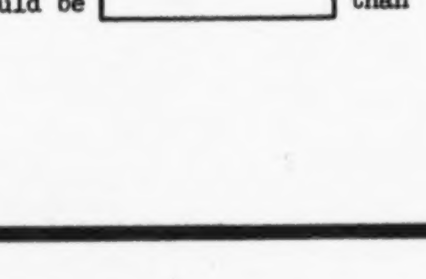
When two waves not in phase come together, * ______ will be produced. If the combined wave fell on a screen, it would be seen as a dark area because the two light waves canceled each other and the combined wave would be ______ than either of them.

C-617

A diffraction grating is a piece of glass with several thousands of lines to the inch ruled on it, very close together. This will produce much ______ bands of light than with fewer slits. If white light is used as the source, a spectrum will be produced on the screen behind the * ______.

C-647

Another way in which light can be plane-polarized is by reflection. We know that when a beam of ordinary light strikes a piece of glass, part of it will be bent upwards, or be ______, and part will be refracted or bent down into the glass.



A·I·R ©1960

END OF UNIT

---

c-638

wave motion (or, vibrations)
stopped (or, destroyed)
horizontal wave motion will get through (or, be present on the other side)
horizontal

---

c-608

phase
two wave lengths
S (to) X

---

c-578

crests (and) troughs (or, troughs and crests)

---

c-548

source
circles

052

A·I·R ©1960

c-527

directions
screen (or, surface, shadow)
shadow

c-557

crests (troughs)
troughs (crests)
λ

c-587

destructive interference
weaker

c-617

brighter
diffraction grating

c-647

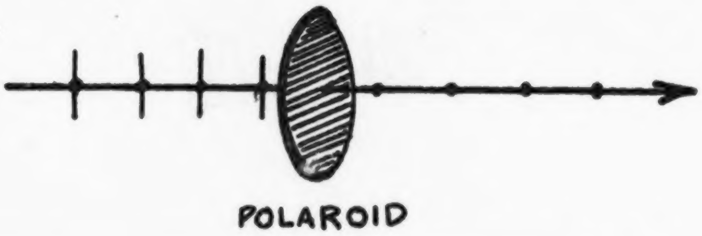
reflected

A·I·R ©1960

END OF UNIT

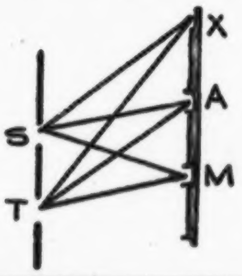
C-638

If the crystals in a sheet of polaroid are horizontal, the vertical [*] of the light waves will be [ ], and only the [**] [ ]. The light leaving the piece of polaroid has wave motion only in the [ ] plane.



C-608

A bright band will appear at each point where the waves from each slit are in [ ]. Thus, the distance from slit T to A, the first bright band from the midpoint, must be exactly one wave length greater than the distance from S to A. Also, the distance from T to X, the second bright band on that side, must be exactly [*] greater than the distance from [$] to [$].



C-578

When two waves run into each other, the kind of interference that results will depend on the way in which the crests and troughs of one wave strike the [ ] and [ ] of the other wave.

C-548

As the waves travel out from their [ ], we see them in the shape of a series of [ ] with ever-increasing radii.

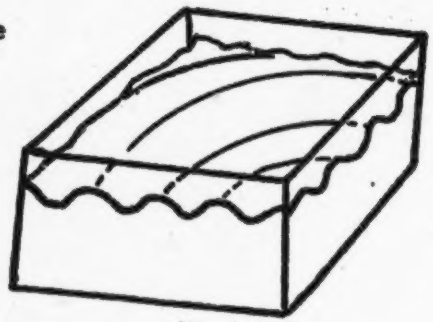
A·I·R ©1960

C-528

Gray, indistinct shadows are cast when the light comes from an * ____________.

C-558

If you looked down at a glass tank of water, you would see that the curved appearance of waves as seen from the top were due to the ________ and ________ of the waves as seen through the glass walls from the side.



C-588

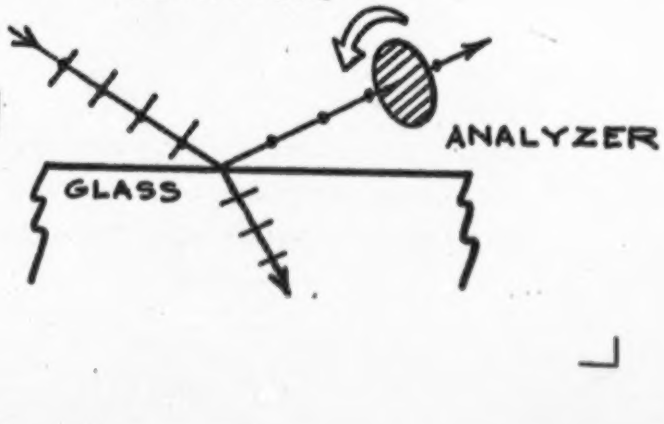
Constructive interference produces a (strong/weak) ________ combined wave which will appear (brighter/darker) ________ than either original wave. Destructive interference produces a ________ combined wave which will appear (brighter/darker) ________ than either original wave.

C-618

A glass with many lines or slits ruled close together is called a * ____________.

C-648

If we rotate an ________; that is, a piece of polaroid, in the path of the reflected ray, we will find that it has been partially * ________ by reflection.



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c-667

selective absorption (as with polaroid), reflection (with an angle of incidence of about 57°), double refraction (using calcite or certain other mineral crystals), and scattering (which occurs when light passes through dust or air)

c-637

plane-polarized
polaroid
horizontal

c-607

M
A (and) B

c-577

weaker

c-547

waves
directions

A·I·R ©1960

(255)

c-528

extended source of light (or, large, nearby source)

c-558

crests (troughs)
troughs (crests)

c-588

strong
brighter
weak
darker

c-618

diffraction grating

c-648

analyzer
polarized (or, plane-polarized)

A·I·R ©1960

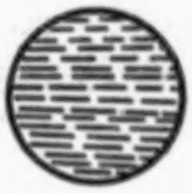
C-667

Polarization can be produced in four ways, these are by ** ______

______.

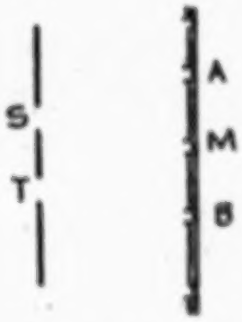
C-637

We can use a sheet of polaroid material to produce * ______ light. Under a microscope, a sheet of ______ is found to contain millions of tiny, needle-like crystals. When the sheet is placed so the crystalline needles are horizontal, only light with ______ wave motion will pass through.



C-607

If a single wave length of light is used, one bright band will always be formed at the midpoint between the two slits. In the figure, this is at point $ ______. Other bands will occur at other points on the screen, such as points $ ______ and $ ______.

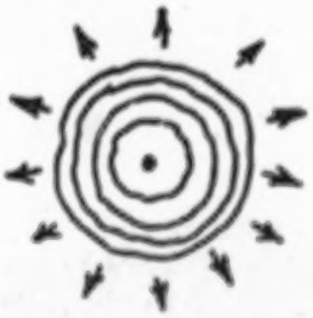


C-577

When the waves from two different sources meet, they affect each other. This is called interference. The combined wave that results may be either stronger or ______ than the original two waves.

C-547

We can observe wave motion if we drop a stone in the middle of a smooth pool of water. The ______ spread out in all ______ from the source; that is, the point where the stone was dropped.



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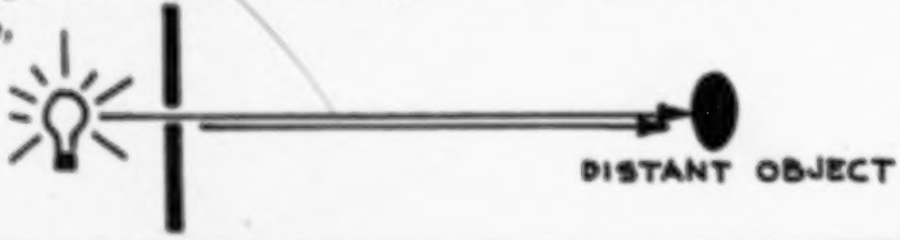
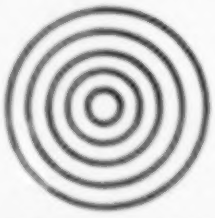
C-529

We can get a small, or ________ source of light by using a pinhole in front of a light bulb. The rays of light hitting a distant object will be just the ones that go through the pinhole. If the object is opaque, the light will form a (black/gray) ________ shadow on a surface behind it.



C-559

As shown in the figure, when we look down at waves from above that have originated at a point source, they appear as a series of ________, each usually representing the crest of a wave. Since the distance from one crest to another is one λ , or one *________, the distance from one circle to the next is also one *________.



C-589

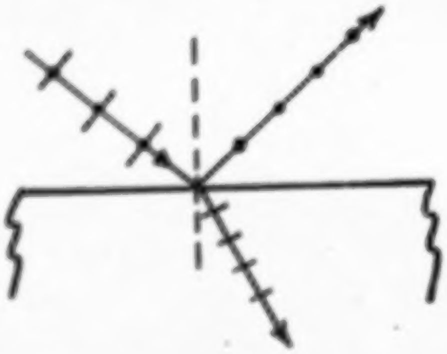
The fuzzy edge of the shadow produced by light waves coming from a small distant source consists of alternate darker and ________ bands close together at the very edge of the ________.

C-619

Just as is the case with diffraction produced by only two slits, the distances between diffraction bands produced by using a *________ depends on λ , the *________ of the light used as a source, on d, the distance between the ________, and D, the distance from the grating to the ________.

C-649

By varying the angle of incidence, we will discover that at a certain angle of ________ almost all the reflected light is plane-________ in a plane parallel to the surface of the glass.



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c-666

has wave motion (or, vibrates) in only one plane

c-636

plane (or, direction)
plane (or, direction)
plane-polarized

c-606

length
color (or, wave length)

c-576

waves

c-546

wave motion

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(259)

c-529

point
black

---

c-559

circles
wave length
wave length

---

c-589

lighter
shadow

---

c-619

diffraction grating
wave length
slits
screen

---

c-649

incidence
polarized

A·I·R ©1960

C-666

Plane-polarized light is light which ** ______________________________ ______________.

C-636

Light which is plane-polarized has wave motion in only one ______________. When the wave motion of light is only horizontal or vertical, or in any one other ______________, it is called * ______________ light.

C-606

Since the points on the screen at which dark and light bands are formed depends on the wave ______________ for each color of light, we can get the most distinct bands by using light of only one ______________. We can also determine the wave length of the light used by measuring the distance between bands, the distance between slits, and the distance from the barrier to the screen.

C-576

If we drop two stones in a pool of water, we will get two sets of ______________ one beginning at each source. After a few moments, the wave fronts will meet.

C-546

The Dutch physicist Huygens (hy-gens) after observing water waves reflecting off a wall in a canal, first advanced the idea that light travels in a * ______________.

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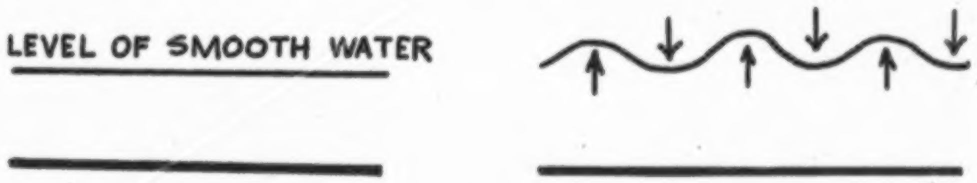
C-530

We get sharp-looking, black shadows if we use a ** ______.

C-560

Comparing smooth water with water that has waves on it, we see that the water is pushed up to form the ______, and is pushed ______ to form the troughs of the waves.



C-590

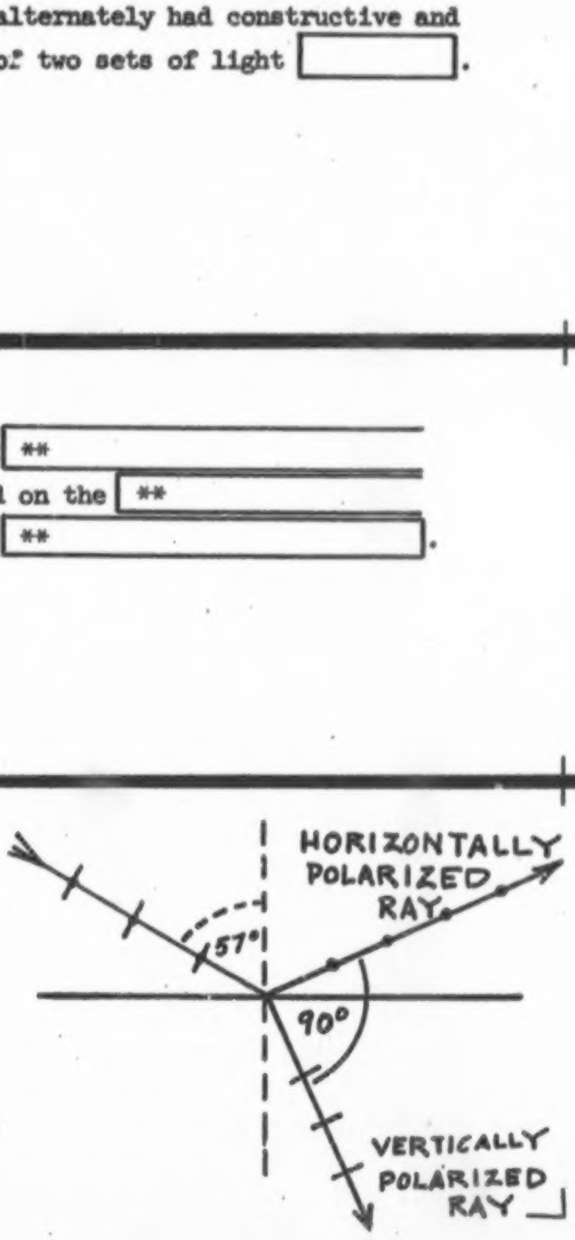
We might expect alternate light and dark bands if we alternately had constructive and ______ interference produced by the combining of two sets of light ______.

C-620

The distance between diffraction bands depends on the ** ______, the ** ______, and on the ** ______, but brightness will be determined by the ** ______.

C-650

As we might expect, the refracted beam, the one that travels through the glass, is also plane-polarized, but the plane of polarization is perpendicular to the surface of the glass. Almost complete ______ of the two beams occurs when the reflected and refracted beams are at ______ angles, or # ______ ° to each other. This occurs, for glass, when the angle of incidence is about 57°.



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c-665

plane-polarized
selective absorption
reflection
calcite (or, quartz)
double refraction

c-635

plane
plane-polarized
only one plane

c-605

interference
different
different

c-575

fuzzy edges (or, bands of light around it)
spread out
diffraction

c-545

wave
wave motion
corpuscles (or, particles)

A·I·R ©1960

c-530

point source of light (or, a small, distant source of light)

---

c-560

crests
down

---

c-590

destructive
waves

---

c-620

wave length of the light
distance between slits
distance to the screen
number of slits (or, lines)

---

c-650

polarization
right (or, 90°)
90

A·I·R ©1960

C-665

Scattering, then, is a fourth way in which light can be * ______. The other three ways are by using a material such as polaroid which causes polarization by * ______, projecting light onto glass or water at about 57°, which causes polarization by ______, and by using certain minerals, such as ______ crystals, which cause polarization due to the * ______ of light.

C-635

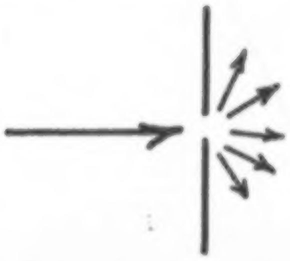
Plane-polarized light is light which vibrates or has transverse wave motion in only one ______. Normally, the light that originates at a source may vibrate in every plane, but * ______ light vibrates in * ______.

C-605

White light is made up of all the colors of the spectrum. The wave length for each spectral color is different, so the points on the screen where constructive and destructive ______ for different colors would occur in a double slit experiment will also be ______; that is, the location of diffraction bands produced by different colors will be ______.

C-575

One reason physicists believe light travels in wave form is that, even when a point source of light is used, the shadow behind an opaque object will have * ______. They also know that light projected through a pinhole or narrow slit, as in the figure, will * ______, even when the rays were originally parallel. Both of these phenomena are known as ______.



C-545

To explain diffraction we can think of light as a ______ motion. As you remember, the fact that light travels slower in water than it does in air was also better explained by thinking of light as a * ______ rather than a stream of ______.

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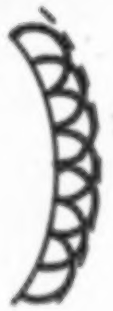
C-531

Since light has ______ propagation, we would expect that the shadow formed by light coming from a distant point source would not only be (dark/light) ______, but that it would have ______ edges.

C-561

This figure shows how the wavelets originating at several points combine to form a new wave, or wave front. The crest of the new wave ______ (the dotted line) appears where the crests of all the ______ line up.



C-591

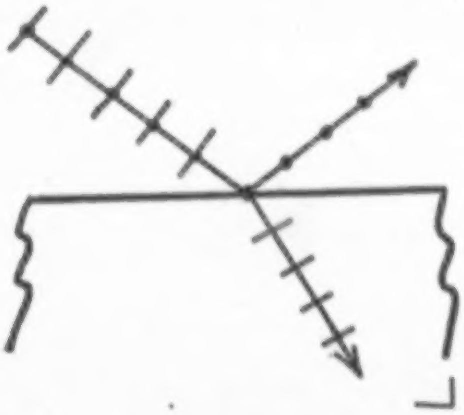
These light and dark bands are called diffraction bands. To see how they are formed, we need to see how light waves going past a barrier or through a slit could produce alternating ______ and ______ interference. This can be understood by studying Young's Double Slit Experiment. It shows how ______ bands can be produced.

C-621

The spreading out of light behind a slit is called ______. It can be explained if we assume that ** ______.

C-651

It is easy to remember which plane of polarization is which for the two rays by thinking of the vertical component as "digging in" to the glass, while the horizontal vibrations, which are parallel to the surface of the glass, are "bounced off" in the ______ ray.



A·I·R ©1960

e-664

blue
scattering

e-634

horizontal
plane

e-604

Double Slit Experiment
diffraction bands
farther apart

e-574

wavelets (or, waves)
front

e-544

diffraction

A·I·R ©1960

c-531

rectilinear
dark
sharp (or, clear)

c-561

front
wavelets

c-591

constructive (and) destructive
diffraction

c-621

diffraction
light is a wave motion (or, light travels in waves)

c-651

reflected

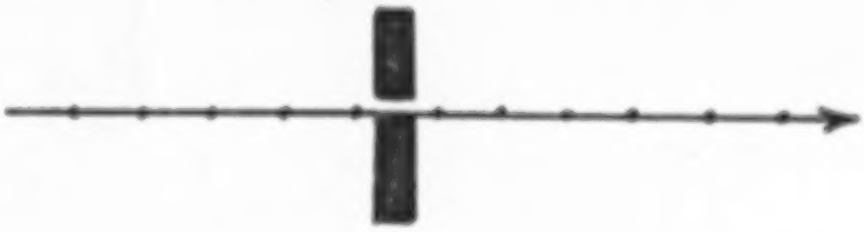
A·I·R ©1960

C-664

When scattering occurs, it is primarily the shorter wave lengths, such as blue, that scatter. This is why the whole sky appears ☐ to us, even though the light coming to us from the sun is white light. In addition, the blue light is partially plane-polarized due to the ☐.

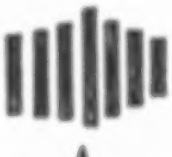
C-634

Similarly, if a light ray passed through a narrow enough horizontal slot, only the ☐ vibrations would get through. Such light would be also called ☐-polarized light.

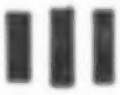


C-604

The farther apart the slits are in Young's ☐ *, the more diffraction bands we will get. Figure A shows more ☐ * than Figure B, so the slits that produced A must be (farther apart/closer together) ☐ than those that produced B.



A



B

C-574

Diffraction can be explained by considering light as made up of small ☐. These originate, according to Huygens, at every point along a wave ☐.

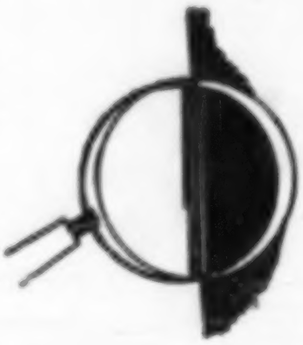
C-544

The spreading out of light from a slit, which we call ☐, can be explained by thinking of light as a wave motion instead of a stream of corpuscles.

A·I·R ©1960

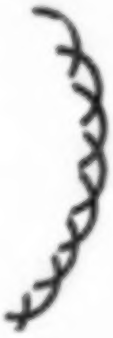
C-532

But, if we observe very closely, even when light is coming from a distant ☐ source, the seemingly sharp edge of the ☐ is not perfectly sharp, but appears fuzzy. To observe the fuzzy edge on a shadow when the light is coming from a pinhole, the screen must be fairly far from the object.



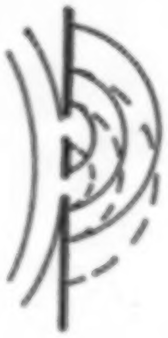
C-562

The crest of a wave, whether it is a water wave or a sound wave or a light wave, is not continuous, but appears wherever the ☐ of ☐ line up. This is called a wave ☐.



C-592

In Young's Double Slit Experiment, a barrier with two slits is used. Thus, at the moment when a big wave struck the barrier, two sets of little waves would start out, one from each ☐. Since the little waves from each slit begin at exactly the same ☐, the little waves from each slit will be in ☐ at several points.

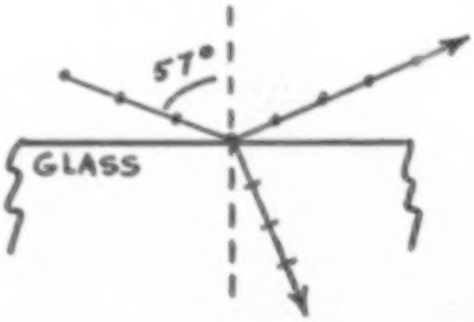


C-622

Diffraction is demonstrated by the ☐ edges on a shadow produced by light originating at a point source, by the ☐** as it passes through a narrow slit or pinhole, and by the diffraction ☐ that are formed when two ☐ are used.

C-652

Complete polarization will occur for glass when the angle of ☐ equals ☐ °, as shown in the figure. The wave motion of the reflected light will be in the ☐ plane and the vibrations of the refracted light will be in the ☐ plane.



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5

c-663

scattering

c-633

wave motion (or, vibrations)
vertical wave motion (or, vibrations)
plane

c-603

Slit
constructive
band
wider

c-573

fuzzy

c-543

diffraction
corpuscles (or, particles)

(270)

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(271)

c-532

point
shadow

---

c-562

crests (of) wavelets
front

---

c-592

slit
moment (or, time)
phase (or, step)

---

c-622

fuzzy
spreading out of light
bands
slits

---

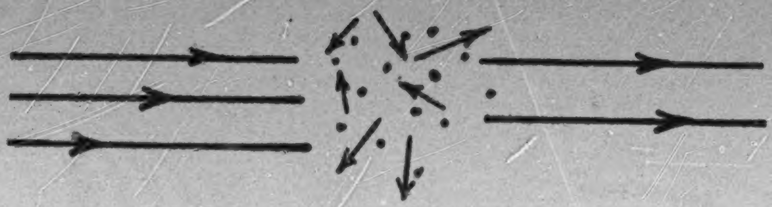
c-652

incidence
57
horizontal
vertical

A·I·R ©1960

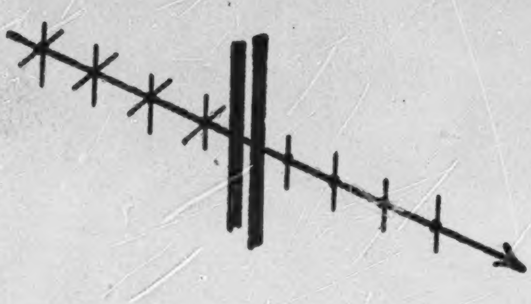
C-663

When light passes through very fine dust or smoke suspended in air, or when it passes through the atmosphere, scattering will occur. This ________ is due to the waves of light causing the particles of dust or the air molecules to vibrate. This vibration causes light to scatter out in all directions.



C-633

The transverse vibrations of a light ray are very small, but if we had a narrow enough vertical slot, the horizontal ________ would theoretically be stopped and only the * ________ would continue on the other side. We call this plane-polarized light, because all the wave motion or vibrations are now in only one ________.

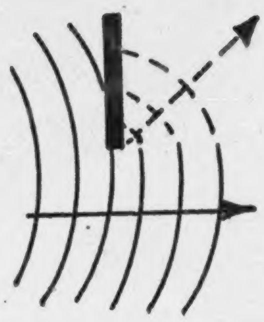


C-603

Where the combined waves in Young's Double ________ Experiment are strong; that is, where ________ interference has occurred, a bright band or stripe of light will result. When the combined waves that strike the screen are weak, a dark ________ will result. The wider the slits, the ________ the bands will be.

C-573

Because of diffraction, a little bit of light spreads into the shadow formed behind an opaque object. This gives the shadow formed by a point source of light its ________ edges.



C-543

The spreading of light when it passes the edge of an opaque object or through a slit is called diffraction (say, dif-frak-shun). This spreading out, or ________ of light cannot be explained if light consists of ________ traveling in straight lines as Newton thought.

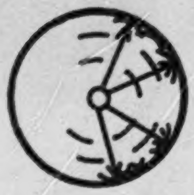
A·I·R ©1960

C-533

The fuzzy edges of a shadow can be seen, with careful observation, not only when an extended source is used, but even when the light comes from a ☐ * .

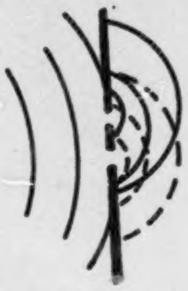
C-563

The wavelets making up a wave spreading out from a point source are all the same distance from the original source, so the whole wave front is ☐ in shape.



C-593

In Young's Double ☐ Experiment, the two new sets of waves will soon run into each other and produce either ☐ * or ☐ * .



C-623

A diffraction grating is something like the barrier used in Young's ☐ * , but it has many more grooves or ☐. In both the barrier used by Young and in the diffraction ☐, the slits are very (close together/far apart) ☐ .

C-653

Brewster's Law states that total polarization will occur when the refracted ray and the reflected ray make an ☐ * with each other. In the case of glass, this occurs when the angle of incidence is about ☐ # °. In other words, ☐ Law states that polarization due to reflection is maximum when the reflected and refracted rays are at right angles.

A·I·R ©1960

c-662

calcite crystal
selective absorption
57
reflection

---

c-632

horizontal slot
vertical slot

---

c-602

whole number
was a whole number of wave lengths

---

c-572

weaker
slit (or, opening)

---

c-542

spread out (in all directions)
slit
pinhole (or, hole)

A·I·R ©1960

c-533

point source

---

c-563

circular (or, spherical, round)

---

c-593

Slit
constructive (destructive) interference
destructive (constructive) interference

---

c-623

Double Slit Experiment
slits
grating
close together

---

c-653

angle of 90°
57
Brewster's

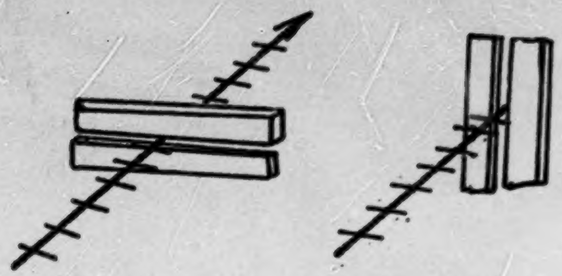
A·I·R ©1960

C-662

Polarization produced by double refraction will occur if light is projected through a quartz crystal or through a * ____. Some kinds of minerals as well as a material called polaroid, also produce polarization, through another process, called * ____. A third way to polarize light is by projecting a beam at a piece of glass at an angle of incidence of about # ____ degrees. This is called polarization by ____.

C-632

Similarly, a wave with horizontal wave motion will pass through a * ____ but will be stopped by a narrow * ____.



C-602

In general, if the difference in the distances from the two slits to a screen is not a * ____ of wave lengths, we would get darker bands. Bright bands would appear where the difference in the distances to the slit ** ____.

C-572

The light waves spreading out beyond the slit are much ____ than the light waves making up the beam that came up to the slit, because not much light energy is transmitted through the narrow ____. However, they can be clearly observed in a photograph.

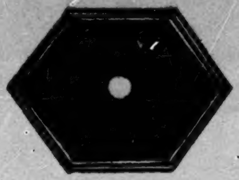
C-542

If Newton's theory were correct, light would not * ____ after it passed through a narrow ____ or a tiny ____.

A·I·R ©1960

C-534

A shadow formed by using an extended source will be grey and have ________ edges. A shadow formed by using a point source will be black, but it will also have * ________ if we examine it closely. The edges will consist of alternating, narrow bands of light and dark, as in the figure.

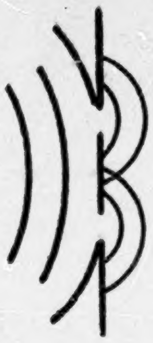


C-564

Since the light emitted by a given source travels with the same velocity in all directions, the crests and the ________ of all the wavelets coming from a given source will line up to form a continuous * ________.

C-594

If light strikes a barrier with two slits in it, we would expect that two new sets of waves starting on out from the two slits would ________ with each other. This experiment, first performed by Thomas Young, is called Young's * ________ Experiment.

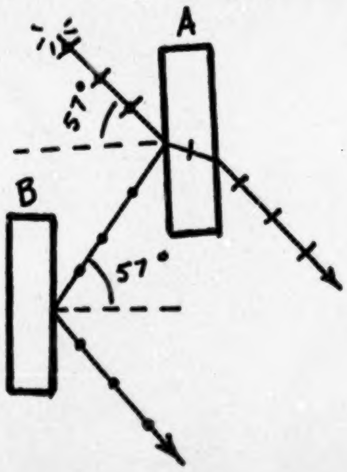


C-624

Transverse means "across," or at right angles to a particular direction. A wave motion which is at right angles to the direction of propagation is a ________ wave. The wave motion of light is in the form of ________ waves or vibrations.

C-654

Suppose, a beam of light is polarized by reflection from a piece of glass (A) which it hits with an incident angle of # ________ °. If it is now again reflected from a second piece (B), which it also hits at an angle of # ________ °, all of the polarized beam will be ________, and none of it will be refracted into piece B.



A·I·R ©1960

c-661

refraction
polarized
plane-polarized
double
absorption

c-631

vertical
horizontal

c-601

phase
other slit
destructive interference
darker
numbers

c-571

radius
weaker (or, less)

c-541

directions
source

A·I·R ©1960

279

c-534

fuzzy
fuzzy edges

---

c-564

troughs
wave front

---

c-594

interfere
Double Slit

---

c-624

transverse
transverse

---

c-654

57
57
reflected

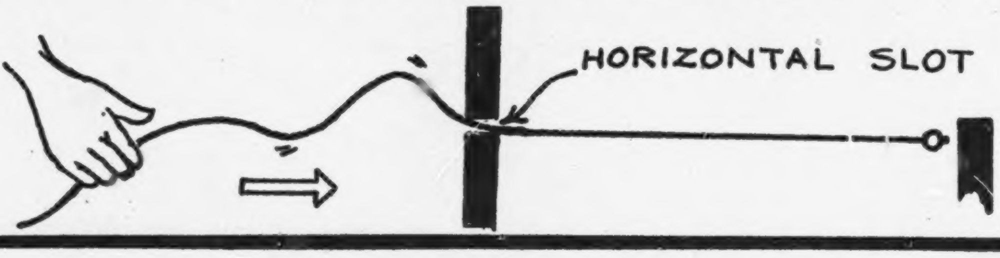
A·I·R ©1960

C-661

When double [ ] occurs, one outgoing ray of light will be plane-[ ] horizontally and the other [*] vertically. Several kinds of mineral crystals will produce polarized light, either through [ ] refraction or selective [ ] .

C-631

If we try to pass the [ ] vibrating rope through a [ ] slot, however, the rope will bump into the sides of the slot and the wave will be stopped.

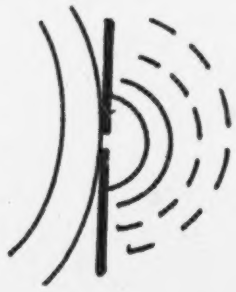


C-601

At other points, when the distance traveled by the light from the two slits differs by $\frac{1}{2}\lambda$, or $1\frac{1}{2}\lambda$, or $2\frac{1}{2}\lambda$, etc., all the light from one slit would be exactly out of [ ] with that from the [*], producing [*]. Thus, a (brighter/darker) [ ] combined wave would result when difference in the distance from the slit to the screen were not whole [ ] of wave lengths.

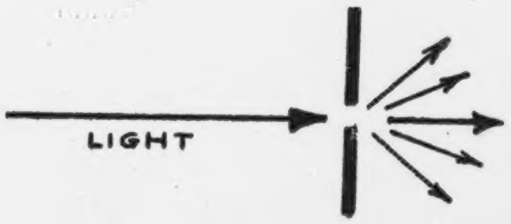
C-571

The new little waves behind the slit start to spread out in circles that have a smaller [ ] than the big wave that hit the barrier, and their strength is much [ ] than the waves that struck the barrier.



C-541

Light from a point source does not go on straight through a slit or a pinhole in a single direction, but rather it spreads out from the slit or hole in all [ ]. It is just as if the slit or hole were a new [ ] of light.



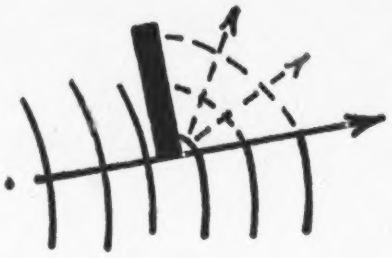
A·I·R ©1960

C-535

The edge of a shadow formed by a point source consists of narrow rings or ______ of alternating light and ______ lines.

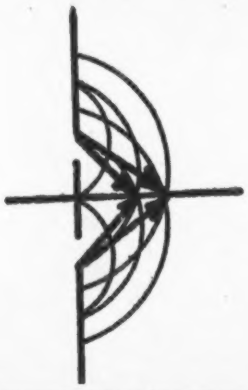
C-565

If we look closely at waves in a pond of water passing by the edge of a post or other barrier, we will see that instead of a completely smooth "shadow" behind the post there are new circles of little ______ starting out from the edge of the barrier.



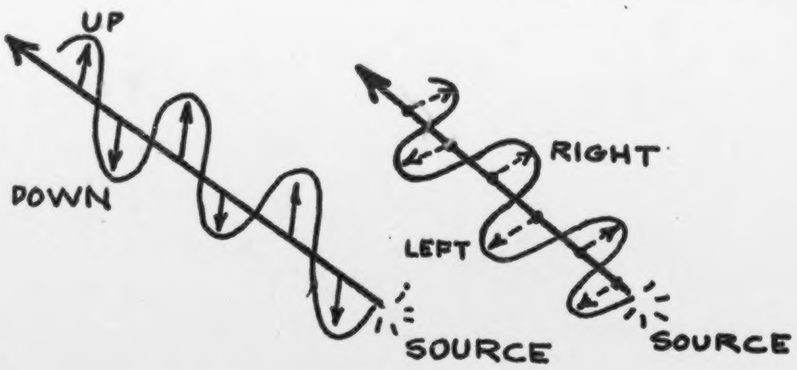
C-595

At the midpoint between the slits the light waves from each slit would have traveled an equal distance. The crests would be in ______, so that ______ interference would be produced. If the combined wave fell on a screen, the illumination would be ______ than that produced by either wave separately.



C-625

The motion of light waves is up-and-down or from side-to-side, but always at right angles to the path traveled by a ray of light. Thus, light waves are all ______ waves.



C-655

By using two pieces of glass, it is possible to demonstrate the plane-polarization of light. If the beam of reflected light were fully polarized by one piece of glass, it would be reflected off a second parallel piece of glass (Fig. 1). But, if the second piece were rotated around to the proper position, then no light would be ______ off the second piece of glass (Fig. 2).

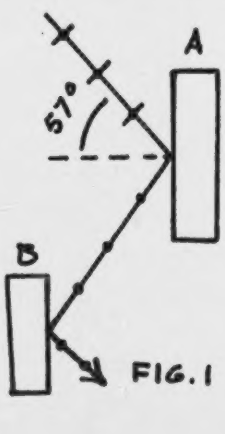


FIG. 1

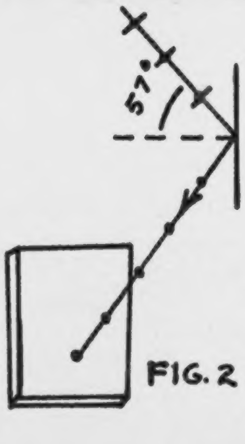


FIG. 2

A·I·R ©1960

c-660

analyzer
be totally absorbed (or, disappear)

c-630

motion (or, vibration)

c-600

constructive interference occurred (or, the waves were in phase)
number

c-570

directions
diffraction

c-540

straight lines
point source (or, distant source)

A·I·R ©1960

c-535

bands (or, circles, stripes)
dark (or, black)

c-565

wavelets (or, waves)

c-595

phase
constructive
brighter (or, greater)

c-625

transverse

c-655

reflected

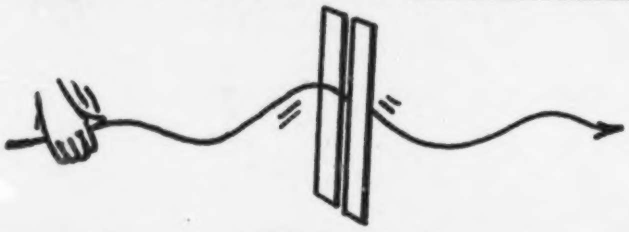
A·I·R ©1960

C-660

If the ________, or sheet of polaroid, is rotated, each of the two fully polarized beams of light coming out of the calcite crystal can alternately be totally absorbed. When either beam is at maximum brightness, the other will * ________ ________.

C-630

We can make a rope vibrate with either horizontal or vertical transverse waves. If we pass the vertically vibrating rope through a narrow vertical slot, the wave ________ will continue on the other side of the slot.



C-600

Young's Double Slit Experiment shows bright bands along the screen where ** ________ ________. This will happen where the distance from the two slits are exactly the same or where they differed by 1 λ, 2 λ, or any other whole ________ of wave lengths.

C-570

Light waves hitting a slit in an opaque object spread out in all ________ on the other side of the barrier. We call this phenomenon ________.

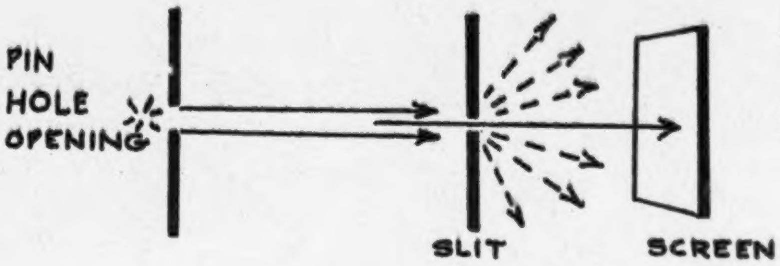
C-540

If light always traveled in perfectly * ________, we would not find fuzzy edges on a shadow formed by a small, or * ________ of light.

A·I·R ©1960

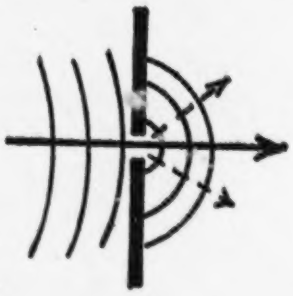
C-536

Also, by very careful observation, we can see that, when light rays from a pinhole source pass through a narrow slit, some light spreads out from the ______ and produces faint, fuzzy bands of light around the central beam.



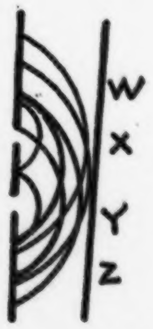
C-566

Also, if any kind of waves hit a barrier that has a slit (or a crack) in it, new little ______ will start on out from the ______. These new little circles of waves are weaker and have a smaller ______ than the radius of the wave that hit the barrier.



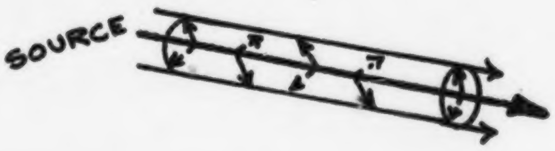
C-596

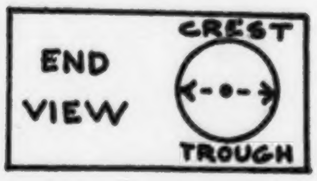
It is also possible for the crests of waves from each slit to line up as they come together in such a way that ______ interference results at other places along the screen. In the figure, the meeting of two crests along the screen is shown at points $ ______ and $ ______.



C-626

If we were able to look at the end of a light ray coming toward us, the transverse, side-to-side wave motion or vibrations would be represented by the horizontal arrows in the circle. Draw in arrows in the end view that would show transverse up-and-down (vertical) vibrations in the end view.





C-656

Light can be polarized by absorption using a piece of polaroid. Also, it can be polarized during reflection. This is a second way in which light can be ______. By arranging two pieces of glass appropriately, it is possible to demonstrate polarization due to ______. By using pieces of polaroid materials, it is possible to demonstrate polarization due to selective ______.

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c-659

polaroid
travel on through

c-629

vertical
horizontal

c-599

constructive interference
line up (are in phase) with the crests of the waves from the other slit

c-569

radius
weaker
speed (or, velocity)

c-539

corpuscles
light (or, rays, corpuscles)
opaque object

A·I·R ©1960

c-536

slit

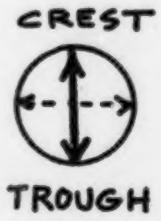
c-566

wavelets (or, waves)
slit
radius

c-596

constructive
X (and) Y

c-626



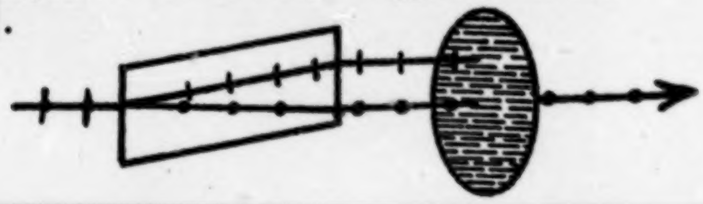
c-656

plane-polarized (or, polarized)
reflection
absorption

A·I·R ©1960

C-659

The differences in polarization of the two rays can be tested with a sheet of ☐ after they pass through the calcite crystal. Since the two rays are now polarized at 90° to each other, we can use an analyzer to make one ray disappear while the other rays will ☐ * .



C-629

In looking sideways at a model of a light ray (Figure 1), we can represent the vertical motion by short lines. The horizontal motion, which would stick out towards us, is just represented by the dots. Figure 2 shows a ray with only (horizontal/vertical) ☐ wave motion, and Figure 3 shows a ray with only ☐ wave motion.

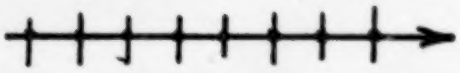
FIG. 1


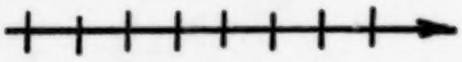
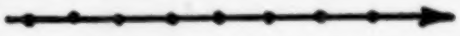
FIG. 2


FIG. 3


C-599

Alternating bands of bright and dark stripes will be formed where the waves from the two slits strike the screen. The bright bands result from ☐ * which occurs when the crests of the waves from one slit ☐ ** .

C-569

The new waves starting out from the slit start out with a smaller ☐ and are (stronger/weaker) ☐ than the big wave that hit it, but they have the same wave length and travel at the same ☐ as the light that struck the barrier.

C-539

If Newton were right, and a ray of light consisted of little particles or ☐ traveling out in perfectly straight lines, all the ☐ would go straight on past the edge of an ☐ * when a shadow was formed, or straight on through a narrow slit or pinhole.

A·I·R ©1960

C-537

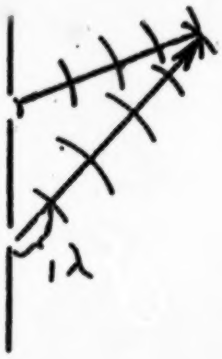
The fuzzy edge of a shadow, or the fringe of light around the main beam that has passed through a narrow __________, means that light actually does not travel in a perfectly * __________ as it passes through a narrow __________ or pinhole.

C-567

As waves of light travel out from a source, they are spread out over more space and hence they get weaker and weaker. This also happens to the wavelets that begin at a slit in a barrier. Since the slit acts as a point * __________, the wavelets get __________ as they get farther away from it.

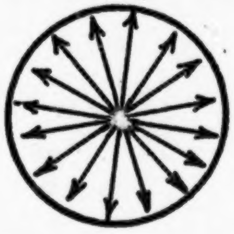
C-597

The waves traveling out from the slits to one side instead of to the midpoint, would have traveled unequal distances to the screen. But, if the distances differed by exactly one wave length (1 λ), two crests would still come together to produce * __________. The combined wave that results will be (stronger/weaker) __________ than either of the two waves.



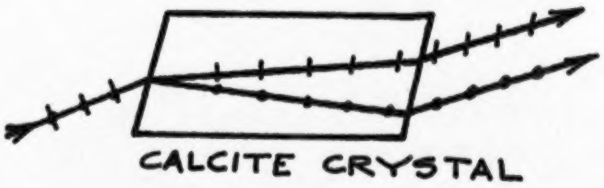
C-627

Physicists have shown that there are not only up-and-down and horizontal wave motions in light waves, but also there can be other forms of __________ wave __________, at all angles. As shown in this diagram of the end view of a light ray, the wave motion may be in any plane.



C-657

Another way in which light can be polarized is by double refraction. This occurs when light passes through a calcite crystal. When a ray of light enters a __________ crystal, it splits into two beams, both of which are polarized. The fact that two rays of light leave the crystal is called __________ refraction.



A·I·R ©1960

c-658

polarized
calcite
double
vertical
ray is polarized in a horizontal plane

c-628

wave motion (or, vibrations)

c-598

trough
destructive
weaker

c-568

weaker (or, less)

c-538

corpuscles

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(291)

c-537

slit
straight line
slit

c-567

source of light
weaker

c-597

constructive interference
stronger

c-627

transverse
motion

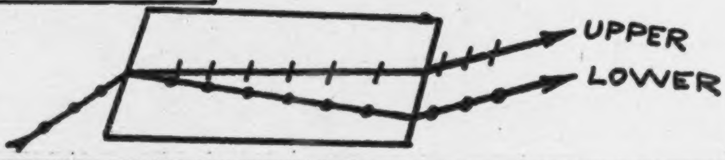
c-657

calcite
double

A·I·R ©1960

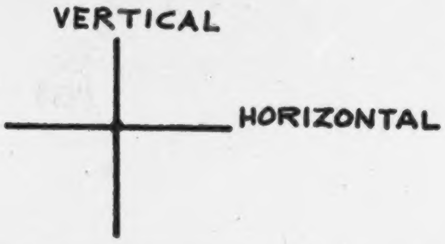
C-658

The two beams of oppositely ________ light formed in a ________ crystal through ________ refraction are polarized in opposite planes. With the crystal turned as shown in the figure, the upper ray is polarized in a ________ plane, and the lower ** ________.



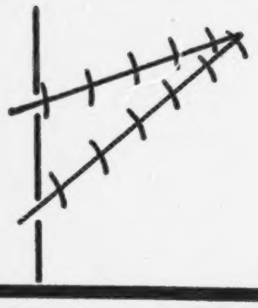
C-628

In dealing with these wave motions, we can, for convenience, show only upward and downward and side-to-side examples of the transverse * ________ of the light.



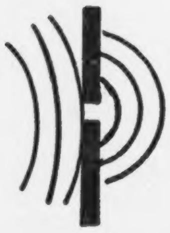
C-598

However, where the distances from the two slits differed by exactly $\frac{1}{2}\lambda$, the crests of one wave would line up with the ________ of the wave from the other slit, producing ________ interference. The combined wave at this point would be (stronger/weaker) ________ than either of the two original waves.



C-568

Since not very much energy can be transmitted through the narrow slit, the strength of the new little waves beyond the slit is much ________ than the strength of the wave that came up to the slit.



C-538

Newton thought that light rays consisted of little particles or corpuscles (say, core-pus-sels) of light. He thought these particles, or ________, always traveled on a straight line unless they were reflected or refracted.

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X (293)

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UNIT SIX

PHOTOMETRY AND REFLECTION REVIEW

Steps C-668 through C-826

296

BEGIN UNIT HERE

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UNIT ENDS HERE

C-668

The investigation of light sources is an important part of the study of optics. The speed, or velocity, of light and the way light rays act as they travel from one place to another are also portions of the study of ______.

C-700

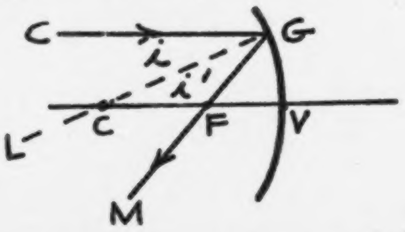
If we increase luminous intensity at the source, we (increase/decrease) ______ the illumination at the surface. However, if luminous intensity is constant, but the distance increases, the illumination is ______.

C-732

Whenever reflection occurs, the angle of incidence, or $ ______ is equal to the angle of reflection, or $ ______. The law of reflection, or i = i', in words means that the ** ______.

C-764

Line CG is an incoming, or ______ ray. Line GL, drawn through the center of curvature, is a ______, and i is the * ______. Line GM shows the path of the reflected ray, and i' is the angle of ______.



C-796

Waves which are out of phase cancel out each other. This occurs when the crest of one wave meets the ______ of the other. In this case, destructive ______ results, and the combined wave will be ______ than either original wave.

A·I·R ©1960

END OF UNIT

---

c-795

in phase
interference
stronger

---

c-763

incident
parallel
center of curvature
normal

---

c-731

reflection
normal

---

c-699

rectilinear propagation of light

A·I·R ©1960

c-668

optics

c-700

increase
decreased (or, less)

c-732

i
i'
angle of incidence equals the angle of reflection

c-764

incident
normal
angle of incidence
reflection

c-796

trough
interference
weaker

A·I·R ©1960

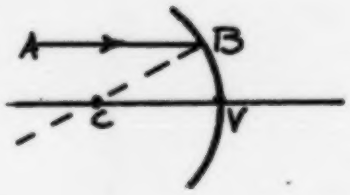
END OF UNIT

C-795

When two waves combine so that their crests come together, we say the waves are *________. This will cause constructive ________; that is, the resulting combined wave will be ________ than either of the two original waves.

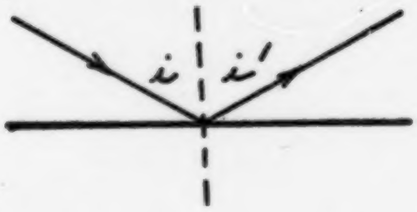
C-763

In the drawing, AB is an incoming or ________ ray, drawn ________ to the principal axis. The line drawn from B through C, the *________, is perpendicular to the curved surface at B, and therefore is the ________ for ray AB.



C-731

In the drawing, the angle of incidence is labeled with an i. The letter i' (say, eye prime) marks the angle of ________. The dotted line is called a ________.



C-699

The fact that light travels in straight lines is referred to as the *________ ________.

A·I·R ©1960

C-669

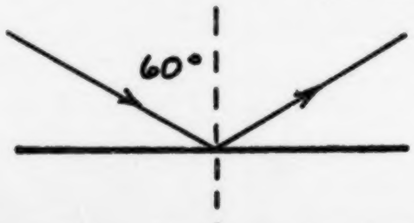
The sun is an important natural source of radiant energy. That part of radiant energy which we can see is called ______.

C-701

The inverse square law states that the ______ on a surface decreases in proportion to the square of the distance to the ______, but increases as the luminous intensity of the source is ______.

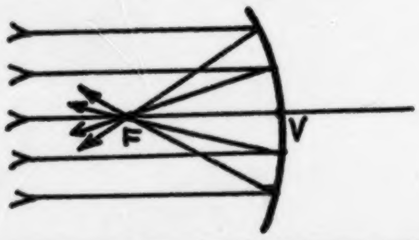
C-733

The * ______ states that i = i', or the angle of ______ must equal the angle of ______. In the figure, if i is 60°, then i' is also # ______ degrees.



C-765

Light rays parallel to the principal axis which strike a concave spherical mirror will meet or converge at the * ______. In the drawing, this point is indicated by the symbol $ ______.



C-797

Light diffraction bands result from constructive interference; dark bands are the result of * ______. These will occur alternately when light from a single point source passes through a double slit barrier.

A·I·R ©1960

c-826

angle of incidence equals the angle of reflection
incident ray and the reflected ray
plane

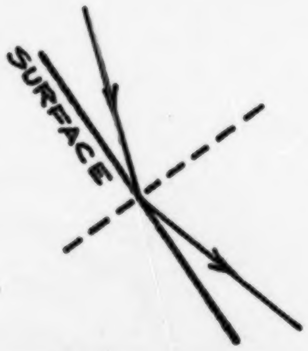
c-794

meet
weaker

c-762

perpendicular
normals

c-730



c-698

straight line
rectilinear propagation

A·I·R ©1960

c-669

light

c-701

illumination
source
increased

c-733

law of reflection
incidence
reflection
60

c-765

focal point
F

c-797

destructive interference

A·I·R ©1960

C-826

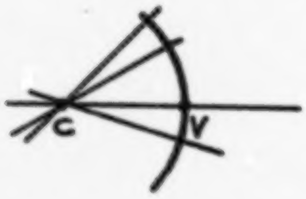
The law of reflection states that the ** ______ and that the ** ______ are in the same ______.

C-794

Interference describes the effect waves have on each other when they ______. The resulting combined wave may be either stronger or ______ than the original waves, depending on whether the waves meet in phase or not.

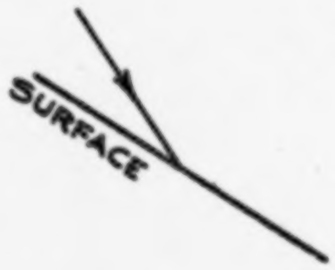
C-762

In the drawing, a principal axis and several secondary axes are shown. Since they are all radii of curvature, they are ______ to the curved surface and can be used as ______.



C-730

Complete this figure by drawing a normal, using a dotted line, and a reflected ray. Show the direction of light in the reflected ray with an arrow.



C-698

The rectilinear propagation of light means that light travels in a * ______. The fact that we cannot see around corners is a very obvious way of proving the straight-line travel, or * ______ of light.

A·I·R ©1960

C-670

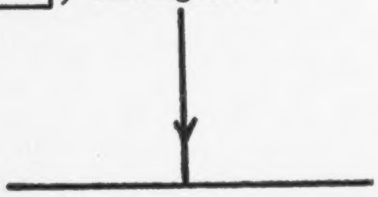
Light is a form of radiant energy. Although we cannot see heat or radio waves, we know that these waves are other forms of [*].

C-702

The inverse square law states that the [ ] of a surface is directly proportional (increases as we increase) to the [*] of the source, and is inversely proportional (decreases as we increase) to the [*] between the light source and the surface, measured perpendicular to the surface.

C-734

An incident ray could be perpendicular to a surface. This is a special case, but this law of reflection still applies. The angle of incidence between the normal and the incident ray is zero degrees. Since, according to the law of reflection, i = [$], the angle of reflection must also be [ ] degrees.



C-766

Parallel incident rays are reflected by a concave spherical mirror so that they meet at the [*].

C-798

In Young's Double Slit Experiment, both constructive and destructive [ ] occur. The resulting light and dark bands of light are called [ ] bands.

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c-825

vibrates (has transverse wave motion) in only one plane

c-793

wavelets
point
diffraction
weaker

c-761

perpendicular
perpendicular
normal

c-729

normal
perpendicular
M

c-697

straight lines

A·I·R ©1960

(307)

c-670

radiant energy

---

c-702

illumination
luminous intensity
square of the distance

---

c-734

i'
zero (or, 0)

---

c-766

focal point

---

c-798

interference
diffraction

A·I·R ©1960

C-825

Light which is plane-polarized is light which ** ______.

C-793

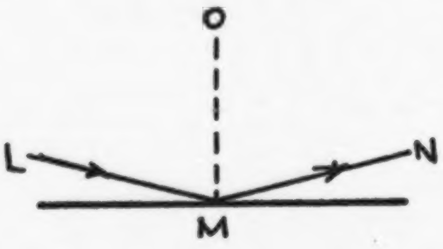
When light passes through a pinhole or narrow slit, new little ______ originate at the slit and spread out in all directions as if it were a new ______ source of light. This is one of the phenomena called ______. Because they spread out, the new waves behind the slit will be (stronger/weaker) ______ than those that came up to the barrier.

C-761

A normal is always ______ to a surface. We can draw a normal for either a plane or a curved surface. If the curved surface is spherical, any radius of curvature will be ______ to the surface and therefore will be a ______.

C-729

A normal is a line perpendicular to a surface. In order to study reflection, we use a normal drawn at the point where reflection occurs. In the figure, line OM is a ______ drawn ______ to the surface at point $ ______.



C-697

If an opaque shield is held near a light source, the area behind the shield is in shadow, because light travels in straight lines. A soldier sighting along a rifle barrel is also making a familiar use of the fact that light travels in * ______.

C-671

The moon is not a source of light. It reflects the sun's rays, but does not * ________.

C-703

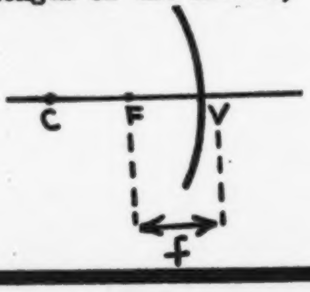
The inverse square law in formula, is written as: illumination = $\frac{\text{luminous intensity}}{\text{distance squared}}$. Using the symbols E for illumination, I for luminous intensity and r for distance, the same formula in symbols would be $ ________.

C-735

The law of reflection states that ** ________ ________. In addition, we know that the incident ray and the * ________ will be in (the same/different) ________ plane, and that the reflected ray will be on the opposite side of the ________ from the incident ray.

C-767

We can measure the distance between V, the ________ of a concave mirror, and F, the * ________. The length of this line is called the ________ length of the mirror, shown in symbol form as a small "f."



C-799

The sun produces white light, which is really a combination of different colored light waves. Each color has a slightly different wave length, or $ ________. The apparatus used in Young's * ________ can also be used to measure ________ length.

A·I·R ©1960

c-824

wave motion
diffraction
diffraction bands
interference

c-792

wavelets
front

c-760

vertex
secondary axis
principal axis

c-728

hallway
operator's eye

c-696

illumination
foot (-candles)

A·I·R ©1960

311

c-671

emit light

c-703

$E = \frac{I}{r^2}$

c-735

the angle of incidence equals the angle of reflection
reflected ray
the same
normal

c-767

vertex
focal point
focal

c-799

λ
Double Slit Experiment
wave

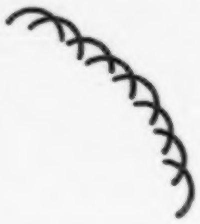
A·I·R ©1960

C-824

Young's Double Slit Experiment demonstrates that light has a *__________, because __________ occurred behind each slit, and *__________ result on the screen due to __________ between the waves coming from each slit.

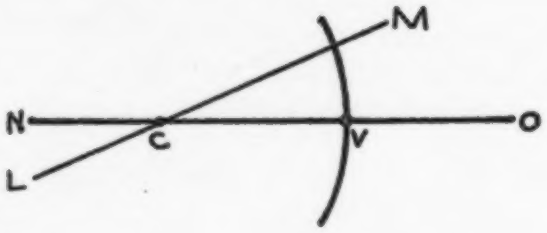
C-792

According to Huygens' theory, light actually travels in little wavelets that originate at all points along a wave front. Where the crests of these little __________ line up, as in the figure, a new wave __________ will appear.



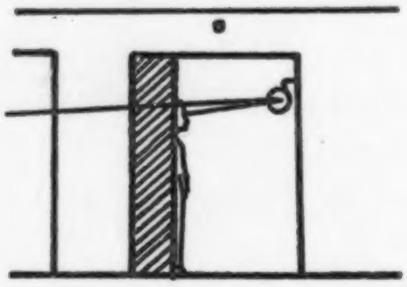
C-760

A secondary axis is a line drawn through the center of curvature to the surface of the mirror at any point except the __________. Line LM is a *__________ of this mirror, but line NO is the *__________.



C-728

An elevator operator uses a small mirror to watch for passengers walking toward the elevator. Light travels from the hallway to the mirror, and is reflected to the operator's eye. In this case, the incident ray of light travels from the __________ to the mirror, and the reflected ray travels from the mirror to the *__________.



C-696

The amount of light on a surface, or __________, is measured in units called __________-candles.

A·I·R ©1960

C-672

Many of the stars we see at night emit light just like our own sun. Although very little of their light reaches us because of the distance involved, these are also natural [   ] of light.

C-704

The formula $E = \frac{I}{r^2}$ is the [*   ] law. In it, E is the symbol for [   ], I is the symbol for [*   ], and r is the symbol for [   ].

C-736

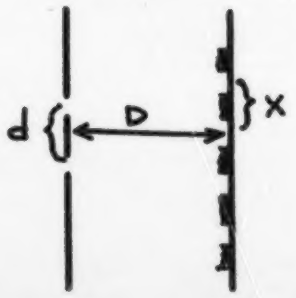
A specular surface is one which is smooth and shiny. We know that images formed by the reflection of light from a smooth or [   ] surface will be clear. A plate glass mirror is an example of a [   ] surface.

C-768

The formula $f = \frac{1}{2}CV$, means that F, the [*   ], will be found midway between [$] and [$]. In other words, the focal length is [**   ].

C-800

To measure wave length, or [$], we need to know D, the [*   ], d, the [*   ], and x, the [*   ]. It is then possible to use the formula $\lambda = \frac{dx}{D}$



A·I·R ©1960

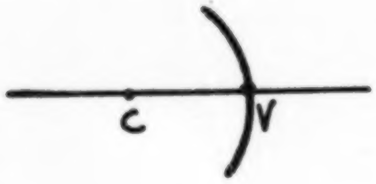
c-823

smooth
rough
specular
diffuse

c-791

crest
trough
wave length

c-759



c-727

reflection
incident
reflected

c-695

luminous intensity
lumens
illuminance

A·I·R ©1960

315

c-672

sources

c-704

inverse square

(E =) illumination (on the surface)

(I =) luminous intensity (of the source)

(r =) distance (from the source to the surface)

c-736

specular

specular

c-768

focal point

C

V

half the distance between the vertex (V) and the center of curvature (C)
(or, half the radius of curvature)

c-800

λ

distance from the barrier (slits) to the screen

the distance between slits

the distance between two adjacent bright bands

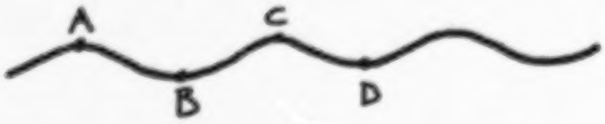
A·I·R ©1960

C-823

A specular surface is a ______ surface, while a diffuse surface is a ______ surface. Images can be formed by reflection from ______ surfaces but not from ______ surfaces.

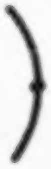
C-791

The motion of a light wave is diagrammed below. Point A is the ______ of the wave. Point B is the ______ of the wave. The distance from A to C, or from B to D is called a * ______, abbreviated λ.



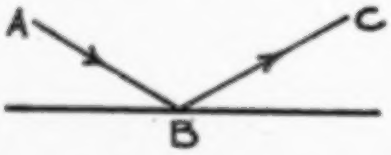
C-759

Draw in the principal axis for this mirror. Label C and V in their proper positions.



C-727

This figure shows the change in direction, or ______ of a ray of light. The incoming, or ______ ray is shown as line AB. The ______ ray is shown as line BC.



C-695

The brightness of a source is called the * ______, measured in candlepower. The flux, or flow of light, measured in ______, is called the ______. When light falls on a surface, we then speak of the illumination on that surface.

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D-673

We use the word incandescent to refer to the fact that substances will give off light when they are heated. The gases of the sun are [ ]. The filament in an electric light bulb also becomes [ ] when it is [ ].

C-705

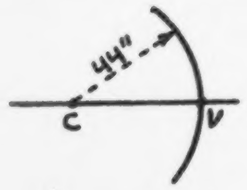
In order to use the formula $E = \frac{I}{r^2}$, that is, the [*] formula, we need information on the units of measurement used. E is expressed in foot-candles, I is expressed in [ ] and r, the [ ], is expressed in feet.

C-737

Diffuse light is light which has been scattered by being reflected from a rough surface. Rough, unglazed wallpaper in a living room furnishes a "softer" light. The reflection from such a surface is called [ ] reflection.

C-769

Find the focal length of a spherical mirror which has a radius of curvature of 44 inches: the distance from C to V is [#] inches, therefore, f is [#] inches.



C-801

A diffraction grating is a piece of glass which has been ruled with a series of very close, equally spaced, parallel grooves. We can produce a spectrum; that is, break up white light into its component [ ] by using a [*].

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c-822

the crests (or troughs) of each wave coincide when the two waves meet

c-790

diffraction
waves
diffraction

c-758

principal axis

c-726

$(\mu =) \frac{c}{v}$

143,077 (or, approximately 143,000)

c-694

amount of light (light flux) that flows from a light source in a given direction
lumens
12.57

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319

c-673

incandescent
incandescent
heated

c-705

inverse square law
candlepower
distance

c-737

diffuse

c-769

44
22

c-801

colors
diffraction grating

A·I·R ©1960

C-822

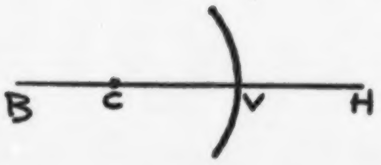
When we say waves are in phase, we mean ** ____________.

C-790

The spreading of light rays as they pass through a narrow slit is called ________. This is evidence for the theory that light travels in ________. The fact that shadows formed by point sources of light have fuzzy edges is also due to ________.

C-758

By drawing a line through the center of curvature and the vertex of a mirror, we can show the principal axis of the mirror. Line BCVH is the * ________ of this mirror.



C-726

If the index of refraction of a material is 1.3, we could substitute in the formula μ = $ ____ to find the speed of light in that material. Since we always know the value of c, we could write $1.3 = \frac{186,000}{v}$, or v = # ________ mi/sec.

C-694

Illuminance is the ** ____________. It is measured in units called ________. One candlepower equals # ____ of these units.

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C-674

A material which is incandescent gives off ______ because it is ______. Incandescent materials may either be ______ sources of light, as the sun or a candle, or ______ sources of light, like an electric light bulb.

C-706

The formula for finding surface illumination when the luminous intensity of a source, and its distance to the surface, are known is $______. A 20 candlepower source, four feet away from a surface will result in a surface illumination of #______ foot-candles.

C-738

An ordinary newspaper is printed on paper which has a rough, unglazed surface. It produces less glare for the reader than a glazed surface; this is a practical use for ______ reflection.

C-770

Rays of light coming from an object which strike either a plane or a curved mirror bounce away, or are ______, from the mirror's surface. For each object point, there is a corresponding point on the ______. All the rays of light leaving any one object point ______ at a single *______.

C-802

Diffraction describes the fact that light **______ ______. It can be explained by the theory that light travels in a ______ motion.

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c-821

center of curvature
vertex
focal point
focal length

c-789

wave
corpuscular

c-757

center of curvature
vertex

c-725

index of refraction equals the velocity of light in a vacuum divided by the velocity of light in another medium

c-693

12.57
10

A·I·R ©1960

c-674

light
heated
natural
artificial

c-706

$E = \frac{I}{r^2}$

$(E = \frac{20}{4^2} = \frac{20}{16} =)$ 1.25 (or, $1\frac{1}{4}$)

c-738

diffuse

c-770

reflected
image
focus (or, converge, meet)
image point

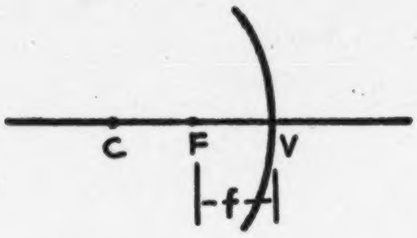
c-802

spreads out at the edge of an opaque surface (or, behind a slit or pinhole)
wave

A·I·R ©1960

C-821

In a spherical mirror diagram, C is the *__________, V is the __________, F is the *__________, and f is the *__________.

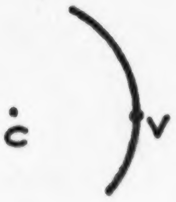


C-789

Diffraction can most reasonably be explained on the basis of Huygens' __________ theory of light in preference to Newton's __________ theory.

C-757

In the figure, point C is the *__________; that is, the center of the sphere of which the mirror is a part. The center of the mirror, on the other hand, is called a vertex. In the figure, V is the __________.



C-725

In symbols, $\mu = \frac{c}{v}$. In words, this formula states that the **__________ __________ __________.

C-693

Since the illuminance of a one candlepower light bulb is 12.57 lumens, the candlepower of any bulb is found by dividing the number of lumens it produces by #__________. The luminous intensity of a bulb producing 125.7 lumens of illuminance is therefore #__________ cp.

A·I·R ©1960

C-675

An artificial source of light, such as a tungsten filament lamp, has a small wire coil which is heated as an electric current passes through it. The wire, or ______, thus becomes ______ and emits light.

C-707

Figure 1 shows a 450 candlepower source which is 3 feet from a surface. The illumination on that surface will be # ______ foot-candles. Figure 2 shows an 800 candlepower source which is 8 feet from a surface. The illumination on that surface will be * ______ ______.

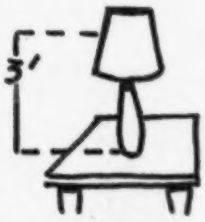


FIG. 1

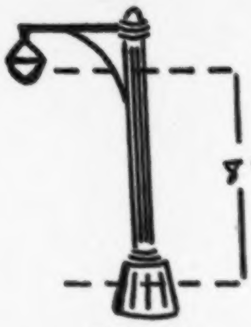


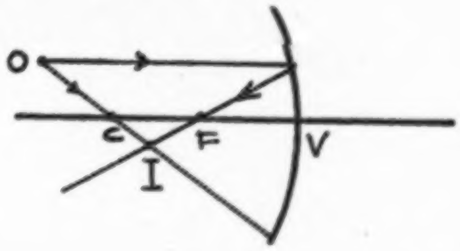
FIG. 2

C-739

Sunlight reflected by a mirror produces a blinding glare. This type of reflection from a smooth and shiny surface is called * ______. In this type of reflection, the reflected rays are all ______ to each other.

C-771

We can locate an image point which corresponds to a given object point by drawing in two lines. One of these usually used is a line from the object to the mirror, parallel to the * ______. A second line, drawn through the center of curvature, to the mirror's surface, called a * ______, will intersect with the other reflected ray at the ______ point.



C-803

Light waves travel in a straight line, but their wave motion, at the same time, is transverse; that is, at right angles to the path of the ray. The appearance of crests and troughs in light waves represent a ______ motion.

A·I·R ©1960

c-820

illumination is proportional to (increases as we increase) the intensity of the source and is inversely proportional to (decreases as there is an increase in) the square of the distance to the source

---

c-788

straight lines

---

c-756

curvature
radius of curvature
center of curvature
radius of curvature

---

c-724

refraction
velocity of light

---

c-692

increase
illuminance
lumens

A·I·R ©1960

c-675

filament
incandescent

c-707

$(\frac{450}{3^2} = \frac{450}{9} =)$ 50
$(\frac{800}{8^2} = \frac{800}{64} =)$ 12.5 foot-candles

c-739

specular reflection
parallel

c-771

principal axis
secondary axis (or, radius of curvature, normal)
image

c-803

transverse

A·I·R ©1960

C-820

The inverse square law, $E = \frac{I}{r^2}$ states that ** ____

____

____

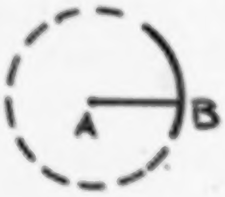
____________.

C-788

Newton's corpuscular theory does not account for the diffraction of light, or the spreading of light rays, as they pass through a pinhole or slit or as they pass by the edge of an opaque object. If Newton had been correct, light rays would travel in perfectly * ____________.

C-756

A spherical mirror is only part of a sphere, but we use the center and radius of that sphere to describe the mirror. We call them the center of ____________ and the * ____________ ____________. For the concave mirror in the figure, point A is the * ____________ and line AB is the * ____________.



C-724

By using the velocity of light in a vacuum and the velocity of light in any other optical medium, we can calculate μ, the index of refraction; that is, index of ____________ equals c divided by the * ____________ ____________ in another optical medium.

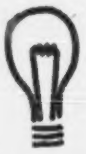
C-692

A one candlepower source of light produces 12.57 lumens of light flux. If we increased the intensity at the source to 5 candlepower, we would (increase/decrease) ____________ the ____________, measured in ____________.

A·I·R © 1960

C-676

The figure shows the kind of light bulb known as a *. The fine spiral wire, or ☐ becomes incandescent when an electric ☐ is sent through it.



C-708

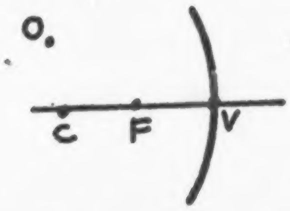
An illuminometer is a device containing a photoelectric cell which is used for measuring the *. Foot-candle meters and photographic exposure meters are both kinds of ☐.

C-740

The "reflection," or ☐, of an object we see by looking at a flat mirror seems to be behind the mirror. Even though the object is always located *, the image formed by a plane mirror is always located *.

C-772

Draw an incident ray parallel to the principal axis from point O. Show the normal and the reflected ray, taking care that i = i'.



C-804

An ordinary light ray may have transverse motion in any plane. When we deal with plane-polarized light, we have stopped all waves having ☐ motion except those in just one ☐.

A·I·R ©1960

c-819

luminous intensity
illuminance
illumination

c-787

does not
point

c-755

spherical
concave

c-723

300,000
speed (velocity) of light
vacuum

c-691

lumen

A·I·R © 1960

c-676

tungsten filament lamp
filament
current

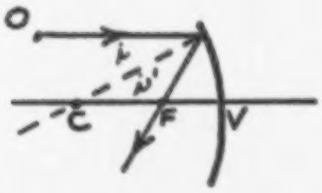
c-708

illumination on a surface
illuminometers

c-740

image
in front of the mirror
behind the mirror

c-772



c-804

transverse
plane

C-819

Candlepower is a measure of * ______. Lumen is the measure of ______. Foot-candle is the measure of ______.

C-787

An extended source of light is a comparatively large source of light. Such a source (does/does not) ______ form dark, sharp-edged shadows. To get a dark shadow, we must use a small or ______ source of light.

C-755

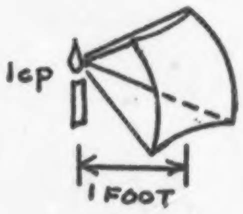
A curved mirror is often a portion of a sphere. When it is, we call it a ______ mirror. Such a mirror may be either convex or ______.

C-723

Either 186,000 mi/sec or # ______ km/sec is a correct value for c, the * ______ ______ in a ______.

C-691

Distance, area and intensity are used to calculate a lumen, the unit of measurement for light flow. The amount of light flowing from a one candlepower source through a one square foot opening which is one foot away from the source is one ______.



A·I·R © 1960

C-677

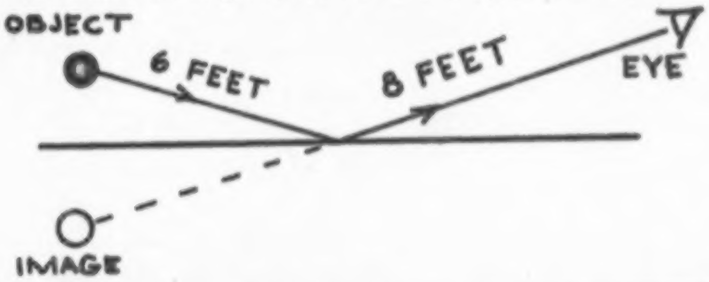
Tungsten is often used in light bulbs, but any material could be heated until it became [ ] and emitted light.

C-709

Photometry is the technique of comparing the luminous intensity of an unknown source with the [*] of a known source of light.

C-741

An image is formed by light which has traveled from the object to the mirror, and then to our eye. The image appears to be as far from our eye as the length of the incident ray plus the length of the [ ] ray. In the figure, this distance would be [#] feet.



C-773

An image formed where rays of light actually meet is called a [ ] image. These images are viewed by projecting them on a screen. An image formed where the light seems to be coming from is called a [ ] image. These images cannot be [*] and must be viewed directly be the eye.

C-805

Light can be polarized by sending it through polaroid, which is composed of close-packed, parallel crystals that permits only those waves to pass through which vibrate in one plane. Light will be [*] if it passes through a sheet of [ ].

A·I·R ©1960

c-818

photometer

photometry

measurement of the luminous intensity of a source of unknown candlepower (by comparing it with a known source)

c-786

straight lines

medium (or, substance)

c-754

concave

convex

c-722

faster

medium

c-690

illuminance

A·I·R ©1960

335

c-677

incandescent

c-709

luminous intensity

c-741

reflected

14

c-773

real

virtual

projected on to a screen

c-805

plane-polarized

polaroid

A·I·R ©1960

C-818

A Joly ☐ is a device used in ☐ which is the ** ☐.

C-786

We use the term rectilinear propagation of light when we mean that light travels in ☐. Light travels in straight lines through glass, water, or any transparent substance. Light cannot travel through an opaque ☐.

C-754

A teacup is an example of a curved surface. Looking into the cup we would see the (concave/convex) ☐ surface. Looking up from beneath the cup we would see the (concave/convex) ☐ surface.

C-722

Light travels (faster/slower) ☐ in a vacuum than it does in any other optical ☐ such as glass or water. Because of this difference in velocity, light will bend as it travels from one medium to another.

C-690

The amount of light which flows through space in a given direction from a light source is called the ☐. It is measured in units called lumens.

A·I·R ©1960

C-678

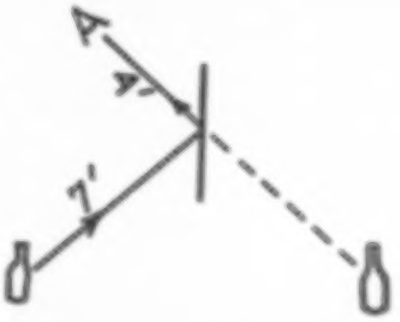
When an electric current passes through a glass tube containing neon gas, the gas will emit light. In other words, we can use a solid such as tungsten, or a gas such as neon, as a source of [ ].

C-710

A "grease spot" or Bunsen photometer is used in [ ]; that is, the comparison of the [*] of two light sources.

C-742

In the figure, the image seems to be [#] feet from our eye. It will be located [ ] the mirror, as if the light had traveled in a [*] along an extension of the [ ] ray.

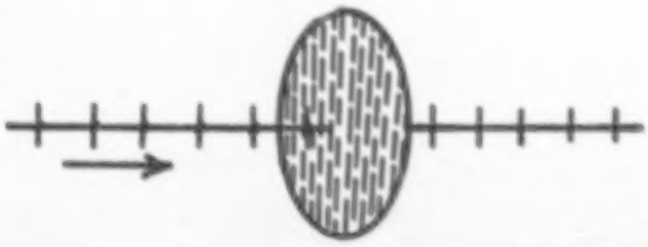


C-774

A real image is always (erect/inverted) [ ], while a virtual image is always [ ]. The kind of image seen in a plane mirror is a [ ] image.

C-806

A sheet of polaroid, turned so that its crystals are vertical, has the equivalent of thousands of small, vertical slits through which light must pass. Waves with vertical transverse motion are therefore (free to continue/obstructed) [ ] while waves with horizontal vibration are (free to continue/obstructed) [ ].



A·I·R ©1960

c-817

study of light (of light sources and how light travels from one place to another)

c-785

parabolic

c-753

angle
increases

c-721

wave
corpuscular theory of light

c-689

illuminance

A·I·R ©1960

c-678

light

---

c-710

photometry
luminous intensities

---

c-742

11
behind
straight line
reflected

---

c-774

inverted
erect (or, upright)
virtual

---

c-806

free to continue
obstructed

A·I·R ©1960

C-817

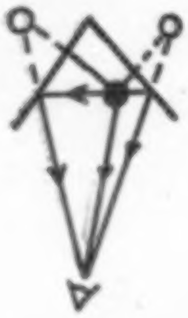
Optics is the ** ______ ______.

C-785

By changing the design of a mirror from a spherical to a parabolic shape, we can construct a mirror which largely eliminates spherical aberration. An automobile headlight projects all light rays in a parallel beam. This indicates that the reflector in the headlight must have a ______ shape.

C-753

When two mirrors are placed at an ______ to each other, we may see several images in addition to the object. As the angle between the mirrors is made smaller, the number of images that can be seen (increases/decreases) ______.



C-721

Proof that light traveled faster in air than in water supported Huygens' ______ theory of light, as opposed to Newton's * ______.

C-689

Illuminance is a way of measuring the amount of light produced by a source. The flow of light, or "light flux" that travels away from the source in any given direction, is the ______.

A·I·R ©1960

C-679

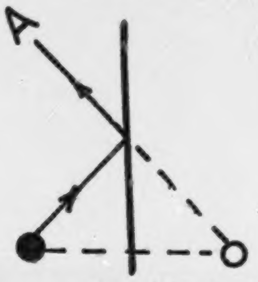
A tungsten filament lamp or a carbon arc lamp emit light because heat is applied until they are ☐. Gases such as neon, or the mercury vapor in a fluorescent lamp, emit light, not because they are heated, but because an ☐ * is passed through them.

C-711

A grease spot or Bunsen ☐, is a simple piece of apparatus used to ☐ the intensities of two different sources of light. Two paraffin blocks, separated by metal foil, were first used by Joly for the same kind of comparison. The paraffin block, or ☐ *, is often used in laboratories to ☐ the luminous intensities of two light sources.

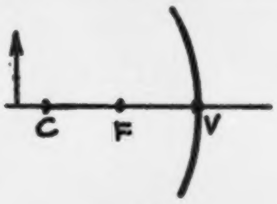
C-743

We can locate the image seen in a plane mirror by drawing a normal; that is, a line ☐ to the surface, from the object to where it intersects with an extension of the reflected ray. In the figure, the hollow circle represents the ☐.



C-775

By drawing the image formed by a spherical concave mirror when the object is farther from the mirror than the center of curvature, you will see that such an image is (real/virtual) ☐, (erect/inverted) ☐, and (larger/smaller) ☐ than the object.



C-807

Selective absorption refers to the ability of material such as ☐ to ☐ **.

A·I·R ©1960

c-816

the light strikes fine particles of dust or smoke

---

c-784

graph (or, chart)
nomograph
$(\frac{1}{f} =) \frac{1}{d_o} + \frac{1}{d_i}$

---

c-752

object

---

c-720

Newton
waves
wave

---

c-688

powerful (or, bright)
candlepower
centimeter
60

A·I·R ©1960

c-679

incandescent
electric current

c-711

photometer
compare
Joly photometer
compare

c-743

perpendicular
image

c-775

real
inverted
smaller

c-807

polaroid
absorb (stop) waves that are vibrating in any plane except one

A·I·R ©1960

C-816

Light waves can be plane-polarized by scattering; that is, when ☐ ** ☐.

C-784

It is possible to draw the relationship between f, d_i, and d_o in graph form. A nomograph is a form of ☐ with which focal length, object distance, or image distance can be calculated in diagram form. By using a ☐, we can get the same results as we would get with the formula $\frac{1}{f}$ = ☐ $.

C-752

In multiple reflection, the image formed by the first mirror serves as the ☐ for the second mirror.

C-720

Huygens' theory of light was opposed to ☐'s corpuscular theory. Huygens believed that light traveled in ☐. Huygens' ☐ theory of light was proved to be more correct than the corpuscular theory of light by the experiments of Fizeau, Foucault, and Michelson.

C-688

Luminous intensity describes how ☐ a given source of light is. It is measured in units called ☐. One square ☐ of molten platinum has a luminous intensity of ☐ # cp.

A·I·R ©1960

C-680

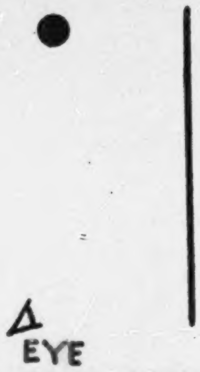
Many electric signs are made of thin glass tubes filled with ____ gas. This gas emits light when an * ____ is passed through it. A fluorescent lamp is filled with mercury vapor. The mercury ____ gives off ultraviolet light when an electric current is passed through it which, in turn, causes a special material forming the inside ____ of the lamp to give off visible light.

C-712

In order to determine the luminous intensity of a source of light of unknown candlepower, we cannot measure it directly, but we can compare the illumination that source gives with ** ____.
This is a technique known as ____.

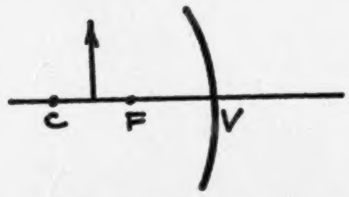
C-744

Complete this figure by locating and drawing the image, using a hollow circle. Be sure, in your drawing that the angle of incidence equals the angle of reflection.



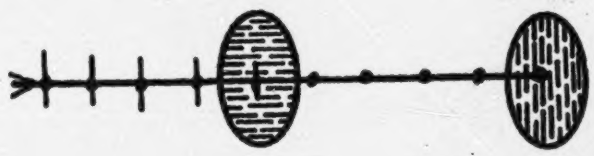
C-776

By drawing the image formed by a spherical concave mirror when the object is between F and C, you will see that such an image is (real/virtual) ____, (erect/inverted), ____ and (larger/smaller) ____ than the object.



C-808

If we plane-polarize light so that only the horizontal vibrations continued, and then placed a vertically-aligned piece of polaroid in the path of the light, the second piece of polaroid would ** ____ due to selective ____ of the horizontal waves.



A·I·R ©1960

c-815

scattering

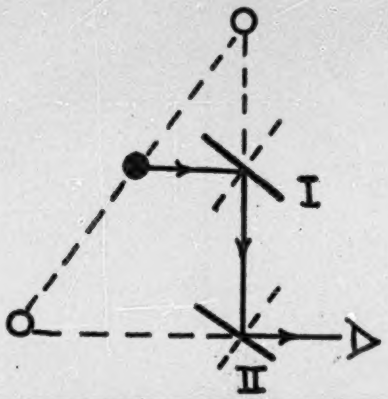
plane-polarization

c-783

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

find the value of (solve for) the third measurement

c-751



c-719

corpuscular theory of light

c-687

luminous intensity (or, candlepower)

A·I·R ©1960

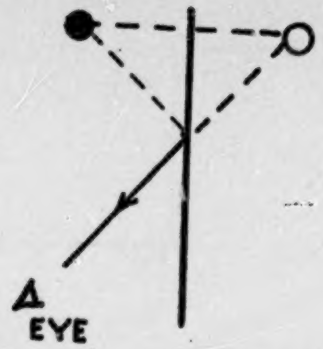
c-680

neon
electric current
vapor
coating

c-712

the illumination given by a source of known candlepower (or, standard)
photometry

c-744



c-776

real
inverted
larger

c-808

stop (absorb) all the remaining light
absorption

A·I·R ©1960

C-815

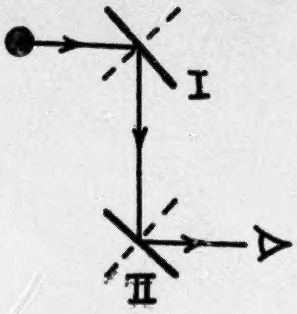
Plane-polarization also occurs when light travels through dust or fine smoke. Light causes the dust particles to vibrate, and the light scatters. Thus, is the fourth way in which * can be produced.

C-783

If we know the focal length and the image distance, we can use the formula $ to find d_o. Knowing any two measurements in this formula, we can ** .

C-751

This is the arrangement of mirrors found in a plane-mirror periscope. Locate the image formed by Mirror I and then locate the image seen by the eye.



C-719

Newton believed that light consists of extremely small particles, or corpuscles. His theory was called the * .

C-687

If two lamps, each producing exactly 50 candlepower, are placed so that one is much farther from an observer than the other, the distant light will seem to be much smaller and dimmer than the nearby light, but we know that the * of each source is exactly the same.

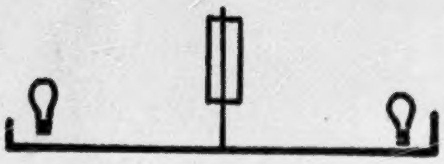
A·I·R ©1960

C-681

A luminous body emits light. The sun is an example of a naturally ______ object; a light bulb is an artificially ______ object.

C-713

To use a Joly ______, we first place it ______ the two light sources and then adjust its position until E = E'; that is, until ** ______.



C-745

Figure A shows a correctly located image and Figure B shows an incorrectly located image. Since, when properly located, the image must be exactly as far ______ the mirror as the object is * ______, Figure B is incorrect. It is also incorrect because the angle ** ______.

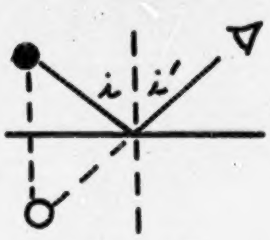


FIG. A

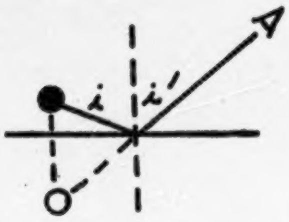


FIG. B

C-777

The image formed by a spherical concave mirror when the object is between F and V (Figure 1) will be virtual, (erect/inverted) ______, and enlarged, or ______. Every image formed by a convex spherical mirror (Figure 2) will also be (real/virtual) ______, but it will be (larger/smaller) ______ than the object.

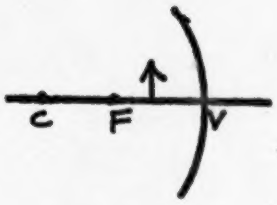


FIG. 1

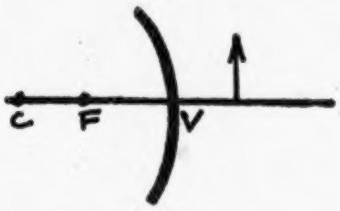


FIG. 2

C-809

By placing polaroid with horizontal crystals behind a sheet of vertically oriented polaroid, we will absorb all of the ______. In this case, the crystals in the two pieces of polaroid are at right angles, or ______ to each other. The use of polaroid demonstrates polarization due to * ______.

A·I·R ©1960

c-814

refraction
calcite
plane-polarized
plane-polarized
vertical

---

c-782

focal length

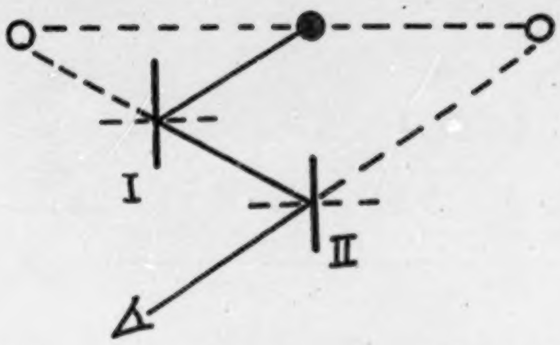
$(\frac{1}{f} =)\ \frac{1}{4}\ (+)\ \frac{1}{12}$

$(\frac{1}{f} = \frac{3}{12} + \frac{1}{12} =)\ \frac{4}{12}$

$(f = \frac{12}{4} =)\ 3$

---

c-750



---

c-718

velocity
186,000
300,000

---

c-686

candlepower
standard candles

A·I·R ©1960

351

c-681

luminous

luminous

c-713

photometer

between

each side is equally bright (the illumination on the unknown side equals the illumination on the known side)

c-745

behind

in front of it (the mirror)

of incidence does not equal the angle of reflection

c-777

erect

magnified

virtual

smaller

c-809

light

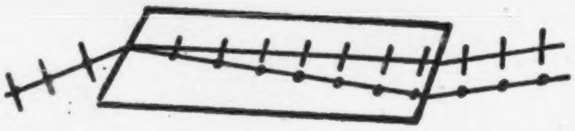
perpendicular

selective absorption

A·I·R ©1960

C-814

When double ________ occurs, one ray of light leaving a crystal of a mineral such as ________ will be * ________ horizontally, and the other will be * ________ in a ________ direction.

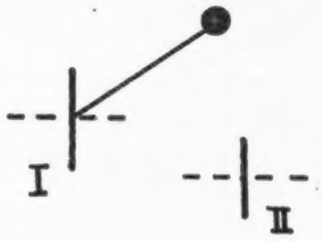


C-782

The formula for finding f, the * ________, is written as $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$. If d_i is 4 inches, and the object distance is 12 inches, we could write the formula as $\frac{1}{f} =$ # ________ + # ________. In this case, $\frac{1}{f} =$ # ________, and f = # ________ inches.

C-750

Complete this drawing by locating the image formed by mirror I, and then the image formed by mirror II. Use a small circle to represent the image.



Δ

C-718

Light travels at a finite or measurable speed. Fizeau's experiments were the first to accurately prove that the speed, or ________ of light could be measured. He found that, in air (or a vacuum), light traveled at # ________ miles per second or # ________ kilometers per second.

C-686

If a one square centimeter of platinum is heated to incandescence, it has a luminous intensity of 60 ________. The platinum square is regularly used now instead of a standard candle. Its light is equal to that produced by sixty * ________.

A·I·R ©1960

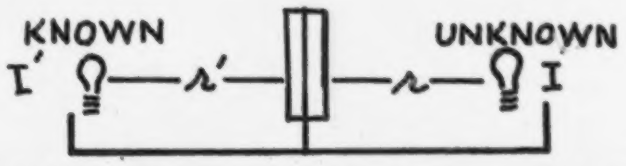
C-682

When we refer to the intensity of a light source, we mean how powerful a source of light it is; that is, its brightness. A strong, bright light has a high luminous intensity; a very dim or weak light has a low * ______.

C-714

Since E, or ______ = $\frac{I}{r^2}$, when E = E', we know that $\frac{I}{r^2}$ = $ ______

Once the two sides of the photometer are equally bright, we can find I, the * ______ of the unknown source, after measuring r', the distance to the known source, and r, the ** ______.

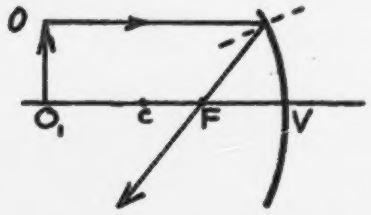


C-746

Fermat's Principle of Least Time states that the path of light in reflection is always the (longest/shortest) ______ possible route. Thus, ______ Principle of * ______ is another way of testing the correctness of a reflection diagram.

C-778

Complete the location of this image. Label the image points I and I' corresponding to O and O'. Draw in the image.



C-810

Light transmitted by one piece of polaroid can be analyzed by a second piece of polaroid placed in the path of the polarized ray. If no light penetrates the second piece of polaroid, called an ______, we know the crystals in each piece are ______ to each other.

A·I·R ©1960

c-813

polarized

c-781

$\frac{1}{d_i}$

$\frac{1}{d_o}$

c-749

straight line
length
path (or, route)

c-717

efficiency
candlepower
watt

c-685

intensity
standard candles
intensity
candlepower

A·I·R ©1960

c-682

luminous intensity

---

c-714

illumination

$\left(\frac{I}{r^2} =\right)\ \frac{I'}{r^{2\prime}}$

luminous intensity (or, candlepower)

distance to the unknown source

---

c-746

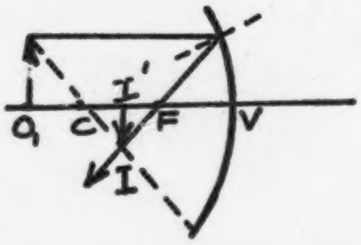
shortest

Fermat's

Least Time

---

c-778



---

c-810

analyzer

perpendicular

A·I·R ©1960

C-813

Crystal formations such as calcite will split a light ray into two polarized beams. This double refraction of light is a third way in which the wave-motion of light can be plane- [ ].

C-781

The formula for finding focal length uses reciprocals; that is, a fraction made by putting the figure "1" over the number. The reciprocal of $f = \frac{1}{f}$; the reciprocal of d_i is [$] and the reciprocal of d_o is [$].

C-749

Regardless of the number of mirrors used, and the number of times the ray of light is reflected, we still see the image as if the light had traveled in a [*]. Also, the image will appear to be as far away as the total [ ] of the [ ] the light took in reaching our eye from the object.

C-717

The efficiency of an electric light bulb is measured in candlepower/watt. The greater the [ ] of a given bulb, the more [ ] of luminous intensity it produces per [ ] of electrical energy.

C-685

Candles made of special materials in a standard size were originally used as a standard of luminous [ ]. These sources, called [*], each had a luminous [ ] of one [ ].

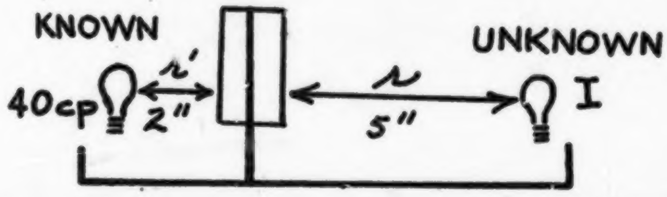
A·I·R ©1960

C-683

The luminous intensity of the sun is very high. An object which emits very little light, a match for example, has a low * .

C-715

If I', the luminous intensity of a standard source, is known to be 40 cp; and, when E = E', r is 5 inches and r' is 2 inches, the value of I can be found by using the formula $\frac{I}{r^2} = \frac{I'}{r'^2}$. In this case, I equals # cp.



C-747

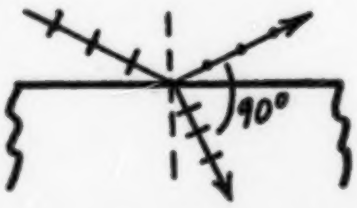
When correctly drawn, a reflection diagram will show that the angle ** , that the image is located ** as the object is in front of it, and that the length of the path of light is the * from the object to the mirror to our eye.

C-779

Object distance, image distance, and focal length for a spherical mirror are all measured along the * , using V, the of the mirror as a starting point. The focal length, for example, is the distance from the to the focal point.

C-811

In most cases, some incident light is reflected and some rays are refracted by a transparent surface. By adjusting the angle of incidence, we can produce polarization by reflection. In the drawing, the reflected and refracted rays are perpendicular to each other, which, according to Brewster's Law, produce maximum * .



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c-812

polarization by reflection
90
incidence

c-780

IV (or, VI)
OV (or, VO)

c-748

multiple

c-716

the same units for both

$(\frac{I}{30^2} = \frac{50}{20^2}, \frac{I}{900} = \frac{50}{400}, I = \frac{4500}{400}, I =)$ 11.25

c-684

luminous intensity

A·I·R ©1960

c-683

luminous intensity

c-715

$(\frac{I}{5^2} = \frac{40}{2^2}, \frac{I}{25} = \frac{40}{4}, \frac{I}{25} = 10, I =)$ 250

c-747

of incidence equals the angle of reflection
as far behind the mirror
shortest possible path

c-779

principal axis
vertex
vertex

c-811

polarization by reflection

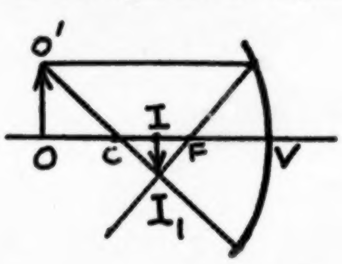
A·I·R ©1960

C-812

Brewster's Law states that maximum [*] will occur when the refracted ray and the reflected ray make an angle of [#] degrees with each other. This occurs, for glass, when the angle of [ ] is 57 degrees.

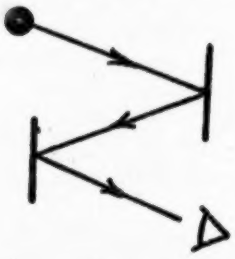
C-780

The symbol for image distance is d_i (say, dee-sub-eye), and the symbol for object distance is d_o (say, dee-sub-oh). In the drawing, d_i is indicated by line [$], and d_o by line [$].



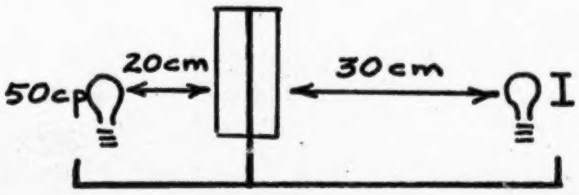
C-748

The drawing illustrates the reflection of light by more than one mirror. This is an example of [ ] reflection.



C-716

It does not make any difference which units of measure we use for r and r' so long as we use [**]. If I' is 50 cp, r is 30 centimeters and r' is 20 centimeters, then I is [#] cp.



C-684

We measure the intensity of light emitted by a luminous body in units called candlepower. The greater the number of candlepower emitted, the greater the [*] of that source.

A·I·R ©1960

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

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UNIT ONE

REFRACTION AND INDEX OF REFRACTION

Steps D-1 through D-128

BEGIN UNIT HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

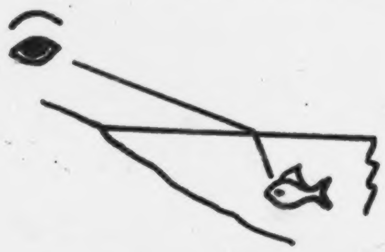
UNIT ENDS HERE

D-1

We call any substance through which light travels a transparent medium. Light can travel through air, glass, water, a diamond, and so forth. Air is a * ______________________; diamond is another example of a * ______________.

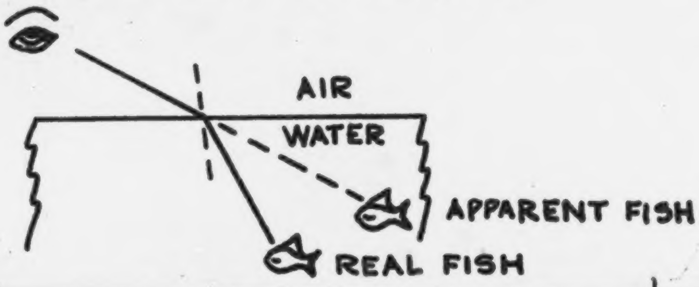
D-27

If we stood at a pond's edge, we might see fishes swimming below the surface. Light has traveled in two media; it was bent, or changed direction, as it crossed the boundary between water and air. This is refracted light, which * ______________ as it traveled from one medium to another.



D-53

A practical example of the refraction of light is the fact that a fish submerged in water is not at the spot at which we seem to see him. This is due to the fact that light bends; that is, it is ________. In this case, the light travels more rapidly in the ______ than it does in the ______.



D-79

The density of a refractive material is related to the speed of light traveling through the medium. Light tends to travel faster in a less dense medium and tends to travel slower in a more dense medium. A vacuum is less dense than air; light will travel ______ in a vacuum than in air. Glass is more dense than air; light will travel ______ in glass than in air.

D-105

The hypotenuse of a right triangle is the longest side. In a right triangle it is also the side opposite the 90° or "right angle". In Fig. 1, the hypotenuse is side $ ____. In Fig. 2, the hypotenuse is side $ ____.

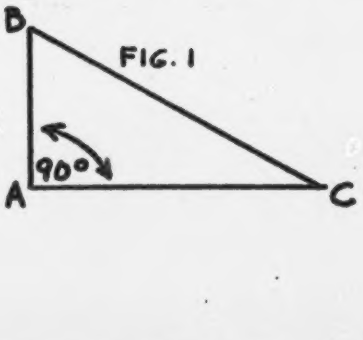


FIG. 1

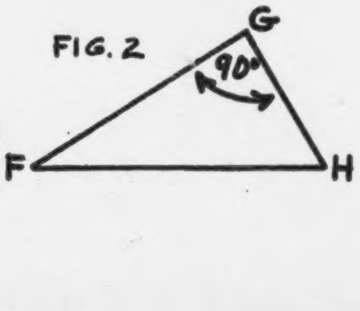


FIG. 2

A·I·R ©1960

d-104

FH

LN

d-78

greater

d-52

DC

d-26

reflected

⑨

A·I·R ©1960

⑦

d-1

transparent medium
transparent medium

d-27

was bent (or, changed direction)

d-53

refracted
air
water

d-79

faster
slower

d-105

BC
FH

A·I·R ©1960

D-104

Every right triangle has one 90° angle. In discussing either of the other angles, we often refer to the side of the triangle which is opposite the angle. In Fig. 1, find angle B. The side of the triangle opposite angle B is side AC. In Fig. 2, find angle G. The side of the triangle opposite angle G is side [$]. In Fig. 3, the side opposite angle M is side [$].

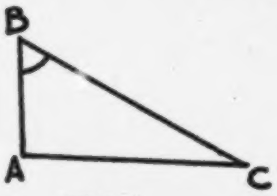


FIG. 1

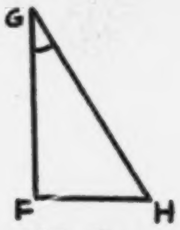


FIG. 2

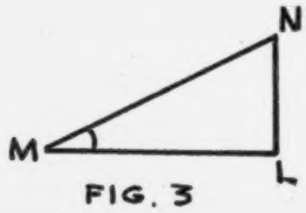
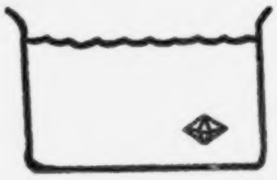


FIG. 3

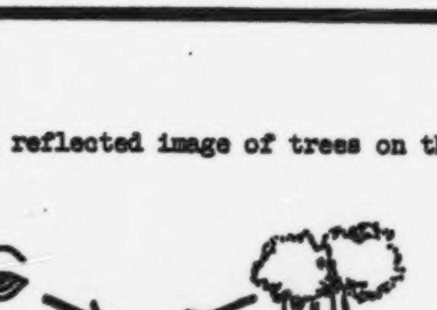
D-78

A diamond sinks in water because the density of the diamond is (greater/less) [ ] than the density of water.



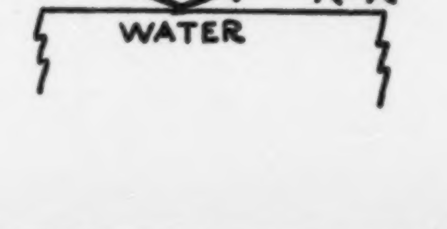
D-52

Light bends away from the normal if the beam travels from a medium in which light travels slowly to one in which it travels more rapidly. In the drawing below, light traveling from glass to air will follow path (DC/DB/DA) [$].



D-26

By looking at the surface of a pond, we might see a reflected image of trees on the far side. This light has changed direction, but traveled only in one medium, air. If the light beam changes direction, but remains in only one medium, we know that this is [ ] light.



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D-2

The plural of medium is media. Air is a medium in which light travels, so is glass. Air and glass are two ______ in which light can travel.

D-28

We use the term refracted light to identify a beam which * ______ as it ** ______.

D-54

Light travels ______ in a vacuum than it does in any other ______.

D-80

The degree of density of a transparent material will affect light's speed to some extent. Light tends to travel faster in materials of * ______ such as a vacuum, and somewhat more slowly in materials of * ______ such as glass.

D-106

The angle shown in Fig. 1 is a 30° angle. It may point in any direction. Fig. 2 is a triangle. Since one angle is 90°, we know that this is a special kind of triangle, a right ______. The side opposite the 30° angle is side $ ______. The hypotenuse is side $ ______.

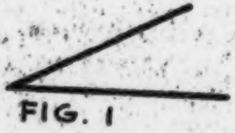

FIG. 1

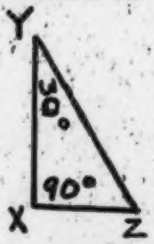

FIG. 2

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END OF UNIT

---

d-103

refraction

---

d-77

dense
air
less dense

---

d-51

slowly
AZ

---

d-25

reflected
refraction

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⑪

d-2

media

d-28

changes direction (or, is bent)
(as it) crosses a boundary into a different medium

d-54

faster
medium

d-80

lower density (or, less density)
higher density (or, more density)

d-106

triangle
XZ
YZ

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END OF UNIT

D-103

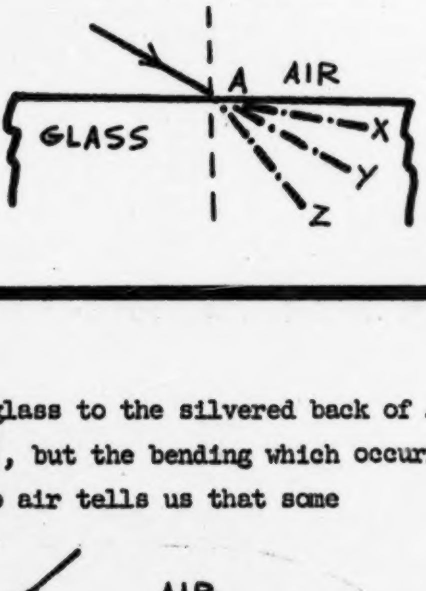
By comparing the extent to which light is bent as it enters a medium, we can compute the index of refraction for that medium. However, we must work with special mathematical numbers and not directly with the degrees of the angles. The sine (the word rhymes with "line") of an angle is written numerically; we will use the sine of the angle of incidence and the sine of the angle of [ ] in our calculation.

D-77

In elementary physics, you learned that a less dense substance "floats" on a more dense substance. Wood floats on water; it is less [ ] than water. Refractive materials also have different densities. For example, water poured into a breaker forced out the air, so we know that water is more dense than [ ]. Ice also floats on water, so we know that ice is also [*] than water.

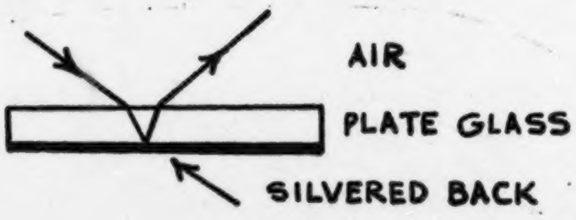
D-51

The refracted ray bends toward the normal line as it passes from one medium to another in which it travels more [ ]. In the drawing, light going from air to glass will follow the path (AX/AY/AZ) [$].



D-25

The drawing below shows light traveling through plate glass to the silvered back of a mirror and bouncing away. We say the light is [ ], but the bending which occurred as the light traveled from the air into glass and from glass to air tells us that some [ ] has also taken place.



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⑬

D-3

Light will be bent or reflected as it strikes a polished surface. This change in the direction of light is called ☐.

D-29

The angle of refraction is formed between the normal and the ☐ ray.

D-55

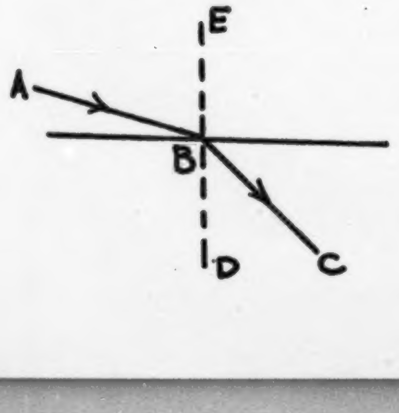
We could compare the numbers 100 and 50 by saying that 100 is twice as large as 50. Mathematically, we can write this as $\frac{100}{50}$ which, you know, is equal to $\frac{2}{1}$ and means that the proportion is two to one. By making such a proportion, we show a comparison or relationship. $\frac{30}{15}$ and $\frac{40}{20}$ are also proportions of ☐ to one.

D-81

While it is correct to speak of the different density of materials, the term index of refraction more accurately describes the velocity of light through the substance. We know though, that a more dense medium usually has a higher index of refraction and a less dense medium tends to have a ☐ index of refraction.

D-107

Because refraction involves the angles of incidence and refraction, we need to know certain mathematical proportions which will help us calculate these angles. The two lines forming the angle of refraction in the drawing below are BC and [\$].



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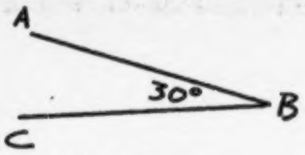
d-128

Snell's (Law)
index (of) refraction
(μ=) 2.0
(μ=) 3.2

d-102



60°

d-76

lowest

d-50

velocity (or, speed)

d-24

reflected
refracted

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⑮

d-3

reflection

d-29

refracted

d-55

two

d-81

lower

d-107

BD

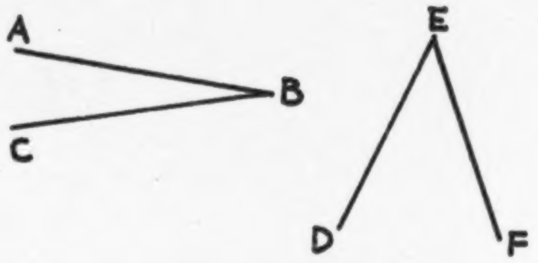
A·I·R ©1960

D-128

☐ Law or $\mu = \frac{\sin i}{\sin r}$, is the usual formula for finding the ☐ of ☐. If sin i is .684 and sin r is .342, $\mu =$ [#]. If sin i is .848 and sin r is .265, $\mu =$ [#].

D-102

In the drawing, lines AB and BC meet at a point to form angle ABC. This is approximately a 30° angle. Write "30°" in the proper area to identify the size of this angle. Angle DEF is twice as large. Angle DEF is an angle of [#] degrees.



D-76

Light travels faster in air than in glass, so air has a lower μ than glass. The velocity of light is faster in a vacuum than in anything else, so a vacuum has the (highest/lowest) ☐ possible index of refraction.

D-50

In our drawings, we often show light traveling from air to water, as in Fig. 1. Sometimes, we show light which originates in water and travels into air. Light is refracted or bent whether it travels from air to water, or as in Fig. 2, from a medium in which light has a low velocity to one in which it has a higher ☐.

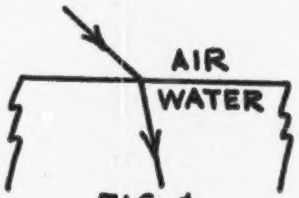


FIG. 1

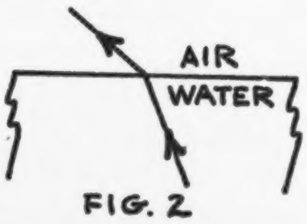
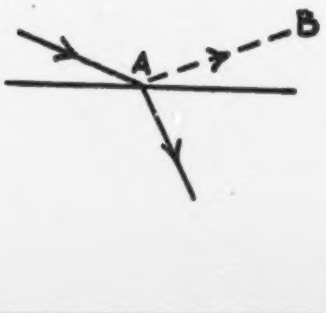


FIG. 2

D-24

We only describe the path of part of the incident ray when we say the ray is refracted, because both reflection and refraction always occur together when light crosses the boundary between two media. In the drawing, some of the light, represented by line AB, is ☐, but for the most part, the light is ☐.



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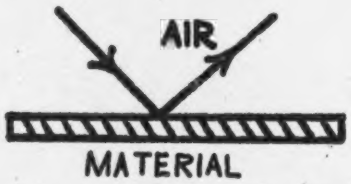
D-4

The figure shows the bending of light due to reflection. As you can see, the ray of light always stays in air; it does not pass through any other [ ].



D-30

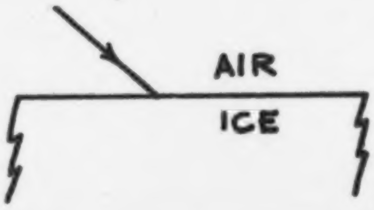
Any transparent medium which bends light passing into it from another medium is called a refractive medium. Glass is a refractive medium. Water, diamonds and air are other examples of [ ] media.

D-56

The proportion $\frac{2}{1}$ is a simpler way of saying $\frac{100}{50}$. In order to get this simple proportion of $\frac{2}{1}$, we have divided [#] by [#].

D-82

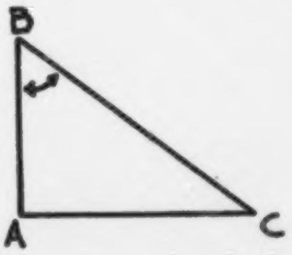
Ice is more dense than air; it has a higher index of [ ]. A light beam traveling from air into ice will bend [ ] the normal as it crosses the boundary into the medium. Draw in the normal and then the path of refraction.



D-108

In a right triangle, the sine of an angle is found by the proportion $\frac{\text{opposite side}}{\text{hypotenuse}}$.

In the drawing, the sine of the angle B is found by dividing the length of the opposite side, AC, by the length of the hypotenuse, BC. $\frac{AC}{BC}$ is the [ ] of angle B.



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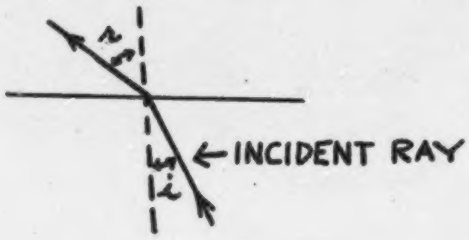
d-127


r
i
INCIDENT RAY

d-101

incidence
refraction

d-75

1.00

d-49

away from the normal

d-23

reflected
refracted

A·I·R ©1960

d-4

medium

d-30

refractive

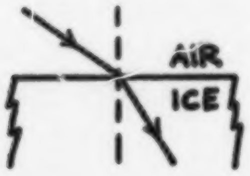
d-56

100 (by) 50

d-82

refraction

toward



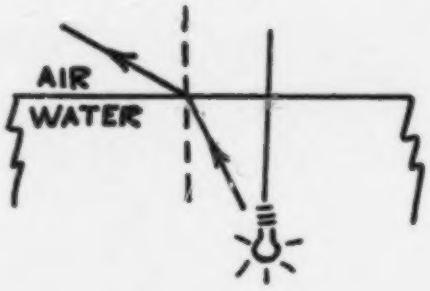
d-108

sine

A·I·R ©1960

D-127

Note the direction of the arrows in the drawing. The light source is in water; it travels toward the air. Label the incident ray, and then label the angles of incidence and refraction.



D-101

We can calculate the index of refraction in terms of the bending of light in different media. This will involve information on the angles which describe the path of light. We will use the angle formed by the incident ray and the normal, and the one formed by the refracted ray and the normal. These are the angle of ______ and the angle of ______.

D-75

Since light travels 186,000 mi/sec in a vacuum, we could compute the index of refraction for a vacuum by dividing, $\frac{186,000}{186,000}$. This comes out to [# ______].

D-49

Light travels slower in a diamond than in air. A beam of light will bend as it crosses the boundary from diamond to air. The direction of bend will be [* ______].

D-23

When light strikes a surface, the beam may be either reflected or refracted. If it remains in the same medium, bouncing from the surface, it is called ______ light. Beams which bend as they travel from one medium into another are called ______ rays.

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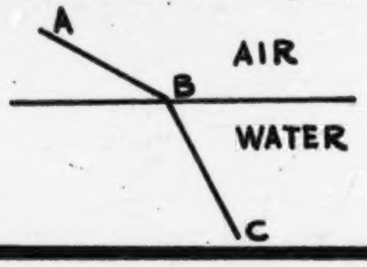
D-5

By experimenting with a light source and a mirror, we can show that light may bend while traveling in only one medium. This change in the direction of light as it strikes a polished surface, is called ☐.

D-31

We speak of light bending as it crosses the boundary between two different media. Bending occurs only at the boundary; that is, the light changes direction at this point. The beam of light represented by the two straight lines has been refracted at point [$] in the drawing.

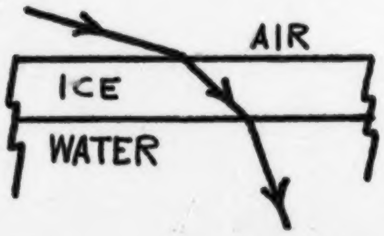


D-57

If a high school had 186 boys and 124 girls, the proportion of boys to girls would be $\frac{186}{124}$ or $\frac{3}{2}$. The boys outnumber the girls. Our proportion means that there are three boys to every [#] girls.

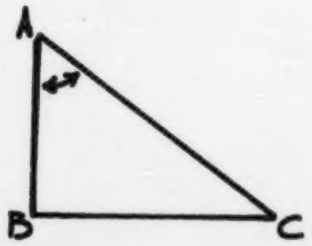
D-83

If light passes through 3 different media, as in the figure, we will need two normals, one for air to ice and one for ice to water.
Draw in the two normals.



D-109

To find the sine of an angle, we first form a right triangle so that measurements of the sides can be taken. Then we can make a mathematical proportion called the sine of the angle. In the figure, the proportion $\frac{BC}{AC}$ is called the ☐ of the angle A.



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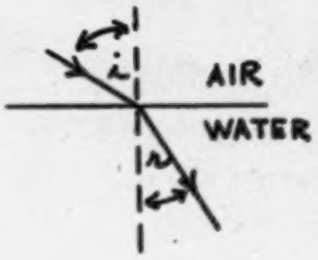
d-126


i
AIR
WATER
r

d-100

toward
away from the normal

d-74

faster

d-48

away

d-22

BF (or, EBF)
BD

A·I·R ©1960

d-5

reflection

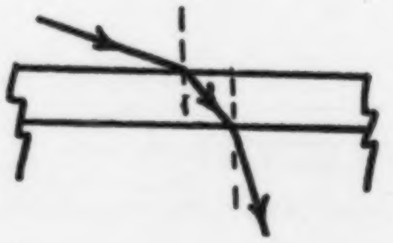
d-31

B

d-57

2

d-83



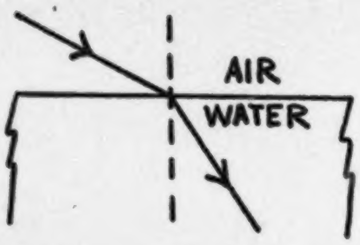
d-109

sine

A·I·R ©1960

D-126

The important elements involved in Snell's Law could be indicated in a diagram. Use "i" and "r" to label the angles which must be measured to use the Snell formula.



D-100

Reviewing what light does as it travels from one medium to another, we know that light will bend ☐ the normal if the second material has a higher index of refraction, or that it will bend [*] as it crosses a boundary into a material of lower refractive index.

D-74

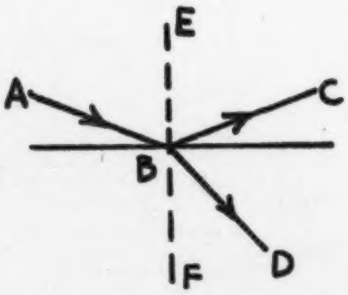
Light would travel ☐ in a medium whose index of refraction is 1.0 than it would in a medium whose refraction index is 1.7.

D-48

Light travels faster in a vacuum than in air. A beam of light which crosses the boundary from air to a vacuum will bend ☐ from the normal.

D-22

In the drawing, the angle of refraction is formed by lines [$] and [$].



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D-6

Light which touches and bounces off a surface is called [ ] light. When we look at a mirror and see a light source, the light ray which traveled from the light source to our eye traveled only through air, a transparent [ ].

D-32

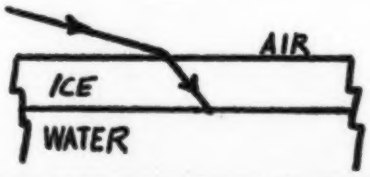
If three different refractive substances were placed, *one at a time*, in the path of the *same* incident ray, there would be no change in the angle of incidence; but the angle of refraction would change each time. In other words, differences in media have no effect on the angle of [ ], but different materials will produce different angles of [ ].

D-58

The proportion of $\frac{\text{186 boys}}{\text{124 girls}}$ could be written as $\frac{3}{2}$, or as $\frac{1.5}{1}$ (say, $\frac{\text{"one point five}}{\text{over one"}}$). There are 1.5 boys to every girl. The proportion of boys to girls is [#] to one.

D-84

Water has a higher index of refraction than ice. A light beam traveling from ice to water will therefore [*] the normal as it crosses the boundary from ice to water. Draw in the two normals and show the bending of this beam as it goes from ice to water.



D-110

To find the sine of an angle (Fig. 1), we first construct a right triangle (Fig. 2). Then, we find the length of the side opposite the angle and divide this number by the length of the hypotenuse. In Fig. 2, we find the sine of angle P by dividing the length of side [$] by the length of side [$].

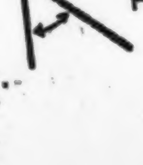


FIG. 1

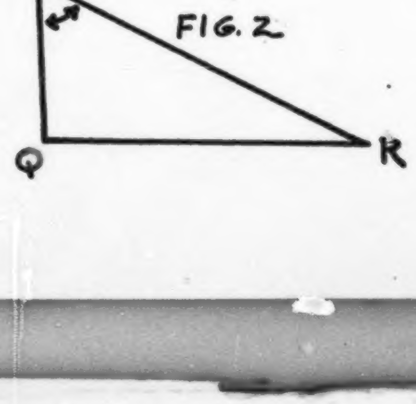


FIG. 2

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d-125

2.4

d-99

bent
medium

d-73

glass
index of refraction

d-47

bend away from the normal

d-21

EB (or, EBF)
AB

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d-6

reflected
medium

---

d-32

incidence
refraction

---

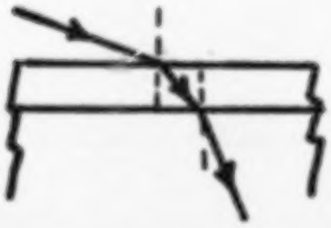
d-58

1.5

---

d-84

bend toward



---

d-110

QR
PR

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D-125

Given the value of .289 as the sine of angle r and .707 as the value of the sine of angle i, calculate the refractive index using Snell's Law. $\mu = \frac{\sin i}{\sin r} = \frac{.707}{.289} =$ ☐ #.

D-99

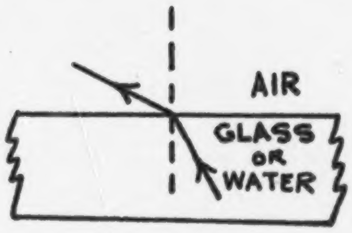
We can compute the index of refraction in two ways, by using the formula, $\mu = \frac{v_1}{v_2}$, or by comparing the degree to which light is ☐ as it travels from one ☐ to another.

D-73

The index of refraction of water is 1.33. The index of refraction for a certain kind of glass is about 1.52. Light would travel more slowly in the ☐, which has a higher ☐ *.

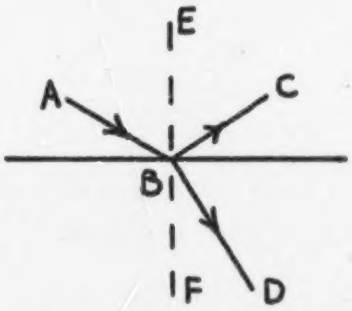
D-47

Light travels faster in air than in glass. When a beam of light goes from glass to air, it will bend away from the normal. When a beam of light goes from water to air, it will also ☐ *.



D-21

In the drawing, the angle of incidence is formed by the normal, line ☐ $ and the incident ray, line ☐ $.



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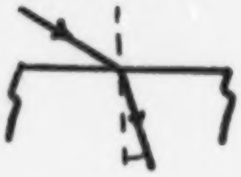
D-7

Light can travel through more than one medium. A ray may travel in air until it reaches a window, then it continues through the glass. This ray of light has traveled through two different ☐.

D-33

The angle between the refracted ray and the normal is called the ☐ * . This angle is a way of describing the path taken by the light after it was ☐ as it crossed the boundary between two different ☐.



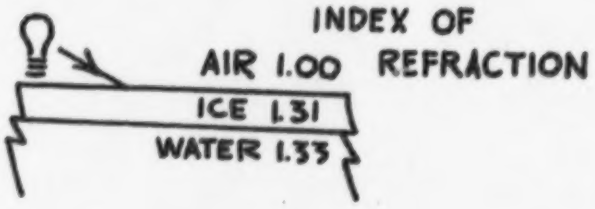
D-59

Instead of comparing numbers of boys and girls, suppose we wanted to compare the velocity (that is, speed) of light in a vacuum (approx. 186,000 mi/sec) with the velocity of light in ordinary glass (approx. 124,000 mi/sec). We make another proportion:

$\frac{186{,}000}{124{,}000} = \frac{186}{124} = 1.5$. In proportion, light travels ☐ # times faster in vacuum than in this particular kind of glass.

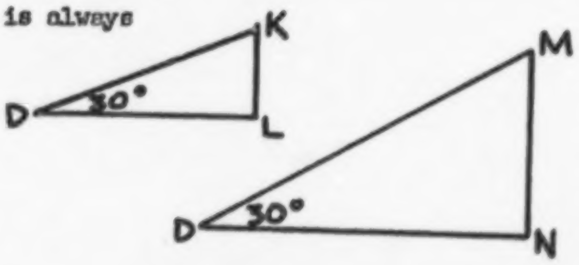
D-85

Light might travel in three media of different indices of refraction -- from air through ice to the water beneath. Draw the path of light in all three media to show refraction or bending which might take place.



D-111

No matter how large we make the right triangle, the sine of an angle will not change. The sine is always the same for a given angle. In the triangles, angle D is 30° in both of them. The sine for angle D is always (the same/different) ☐.



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d-124

$(\mu =)\ \frac{\sin i}{\sin r}$

Snell's (Law)

---

d-98

more
bent

---

d-72

index (of) refraction

---

d-46

slower
toward

---

d-20

angle (of) incidence
angle (of) reflection
angle (of) refraction

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㉛

d-7

media

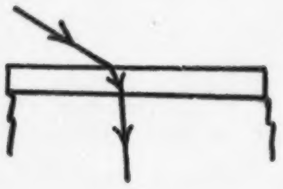
d-33

angle of refraction
bent
media

d-59

1.5

d-85



d-111

the same

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D-124

The formula for index of refraction based on the sines of angles is $\mu =$ $ ________ .

This is known as ________ Law.

D-98

The greater the index of refraction, the ________ light will be bent. This allows us to compute the index of refraction by knowing the degree to which light is ________ as it enters or leaves a medium.

D-72

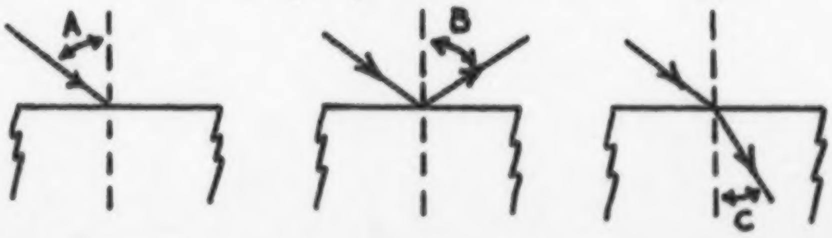
Light travels more slowly in a diamond than in water. The index of refraction of a diamond is 2.4; the index of refraction of air is 1.0. Light travels slower in media having a higher ________ of ________.

D-46

Light has a higher velocity in traveling in water than in diamond. Therefore, when a beam of light crosses the boundary from water to a diamond, the beam will travel ________ than it did in the water and it will bend ________ the normal.

D-20

In the drawings below, the angle A is the ________ of ________, angle B is the ________ of ________ and angle C is the ________ of ________.



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D-8

Light also bends as it goes from one medium to another -- from air to a diamond, for example. This change in the direction of light is called refraction. Light, therefore, bends in two ways: (1) by reflection in a single medium (2) by ☐ as it crosses the boundary between two different media.

D-34

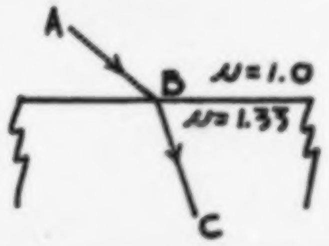
After light has been bent as it passes from one medium to another, the rays of light form an angle with the normal. Whether it is bent away from the normal, or toward the normal, we call this the angle of ☐.

D-60

In refraction, we use the proportion of velocity of light in a vacuum to velocity of light in some other medium. It is called the index of refraction of the denser medium. The formula $\frac{\text{speed of light in a vacuum}}{\text{speed of light in glass}}$ gives us the ☐ of refraction for glass.

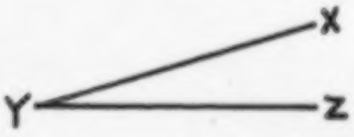
D-86

In the diagram below, line BC shows that light is bent or ☐. Further, although we cannot see the difference, we know that the speed of light is different in media of different refractive indices. Light will travel more ☐ as it travels from B to C than it did in going from A to B.



D-112

We can make a right triangle by drawing a line perpendicular to one of the two sides of an angle. Make a right triangle based on angle Y.



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d-123

Snell's
incidence
refraction

d-97

high
low index of refraction

d-71

index of refraction for a diamond
186,000
2.4

d-45

less (or, slower)
toward

d-19

refraction

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d-8

refraction

d-34

refraction

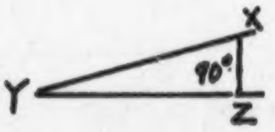
d-60

index

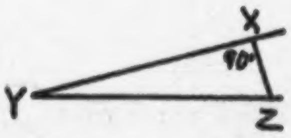
d-86

refracted
slowly

d-112



OR



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D-123

The formula $\mu = \frac{\sin i}{\sin r}$ is known as Snell's Law of Refraction. We can use ______ Law to find the index of refraction if we know the sines of the angles of ______ and ______.

D-97

Different materials bend light entering them to a different degree. A medium which causes light to bend greatly has a ______ index of refraction. A medium which bends light entering only slightly has a * ______.

D-71

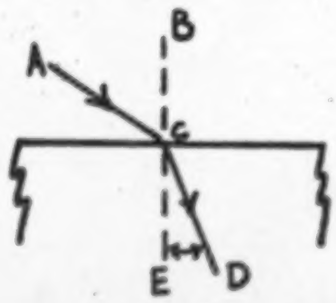
The velocity of light in a vacuum is 186,000 miles per second (or mi/sec). Suppose we knew that the velocity of light in a diamond is about 77,500 mi/sec. We could then compute using the formula $\mu = \frac{v_1}{v_2} = \frac{186,000}{77,500}$. The value of μ, or the ** ______ could therefore be found by dividing # ______ by 77,500 which comes out to # ______.

D-45

Light travels faster in air than in water. As a beam of light crosses the boundary from air into water, its velocity becomes ______ and bends ______ the normal.

D-19

We use the incident ray and the normal to find the angle of incidence; we use the refracted ray and the normal to find the angle of refraction. In the drawing, BCE is the normal and CD is the refracted ray. The angle between lines CE and CD is the angle of ______.



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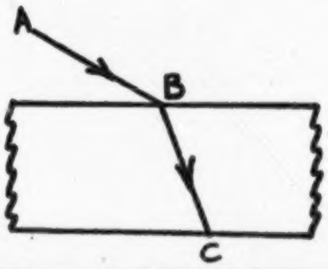
D-9

Refraction is the bending of light rays as they go from one transparent ______ to another.

D-35

The accompanying diagram shows an incident ray, AB, and a refracted ray, BC. Draw in, with a dotted line, a "normal" line, from which the angles of incidence and refraction are measured.



D-61

By setting up a proportion, we can find the index of refraction for ice, for diamond or any other refractive medium. The fastest speed (or velocity) of light; that is, its speed in a ______, is always written above the line in the proportion. This figure is divided by the speed of light in the other ______ medium, which is written ______ the line in the proportion.

D-87

The normal is always formed by a line ______ to the surface. Draw normals for the three figures.

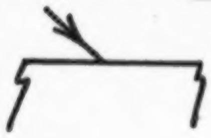


FIG. 1

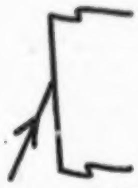


FIG. 2

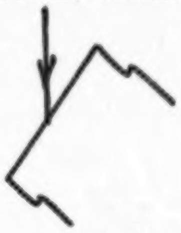
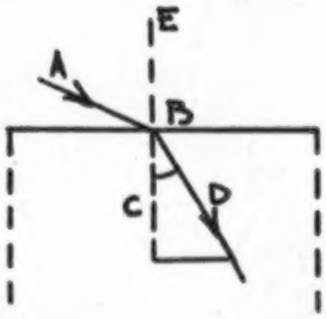


FIG. 3

D-113

In the figure, the angle of refraction is shown by lines CB and $______. We have made a right triangle by drawing line CD perpendicular to the normal. The hypotenuse of this right triangle is side $______. The side of the triangle opposite the angle of refraction is $______.



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d-122

$\mu = \frac{v_1}{v_2}$

$\mu = \frac{\sin i}{\sin r}$

vacuum

medium

d-96

bend

d-70

3.5

d-44

toward the normal

d-18

angle (of) reflection

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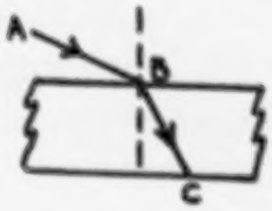
d-9

medium

d-35

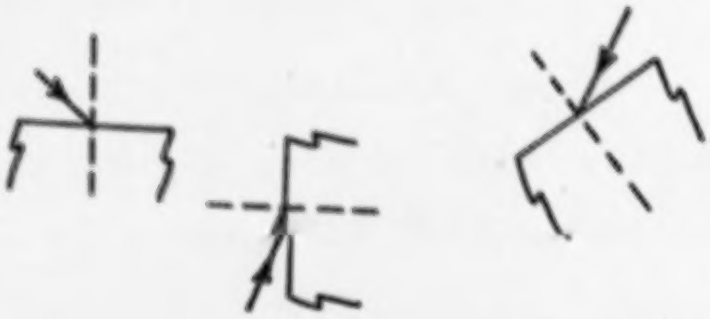


d-61

vacuum
refractive
below

d-87

perpendicular



d-113

BD
BD
CD

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D-122

We can compute μ in two ways. One is by using velocities in the formula $\mu = \boxed{\$\quad}$

and the other is using the amount light is bent during refraction in the formula $\mu = \boxed{\$\quad}$

The first formula is a proportion of the velocity of light in a ☐ divided by the velocity of light in another transparent ☐.

D-96

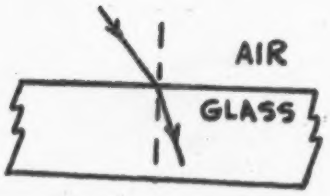
We found that we could calculate the index of refraction by comparing two different speeds of light in media by using the formula $\frac{v_1}{v_2}$. We also know that light bends differently in various media. The amount light will ☐ depends on the medium.

D-70

Now, try dividing $\frac{147,000}{42,000}$. The answer is $\boxed{\#\quad}$.

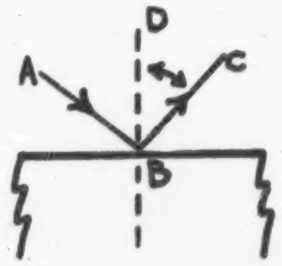
D-44

When light goes from a medium in which it has a high velocity to a medium in which it travels less rapidly, it bends toward the normal. For example, when light goes from air to glass, it bends $\boxed{*\qquad\qquad}$.



D-18

The angle of reflection is formed between the normal and the path of the reflected ray. In the drawing, the reflected ray is BC, and the angle between DB and BC is therefore the ☐ of ☐.



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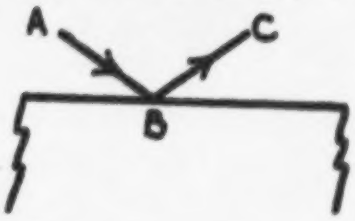
D-10

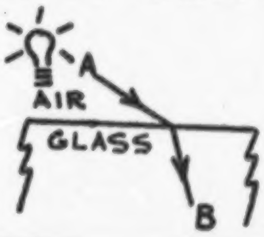
When you studied mirrors, you learned that light was reflected from many kinds of surfaces. The incident ray (or, incoming beam of light) touched the surface; the light which bounced off or was reflected was known as the reflected ray.

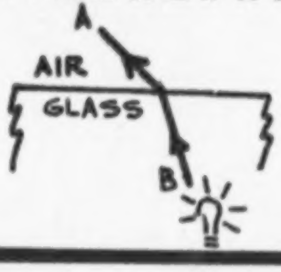
In the drawing, line AB is the ________ ray and
line BC marks the path of the ________ ray.



D-36

Light rays are reversible; that is, the rays will follow exactly the same path if the light source were moved to the other end. We could make light travel from A to B or, by placing the light at B, make light travel from [\$] to [\$].





D-62

If we were to measure the speed of light in ice and use this number in the formula:

$$\frac{\text{speed of light in a vacuum}}{\text{speed of light in ice}} = \text{index of refraction for ice,}$$

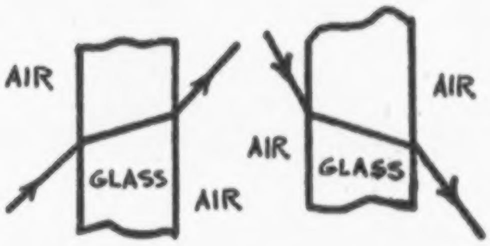
we would have:

$$\frac{186{,}000}{143{,}000} = \frac{186}{143} = 1.3\ .$$

In this example, 1.3 is the [*] for ice.

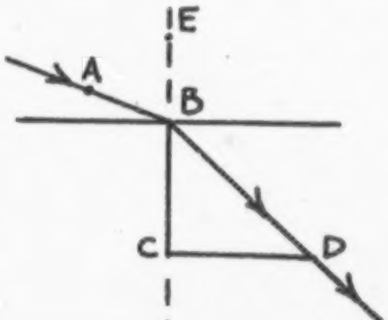
D-88

As light passes through a piece of glass, it is ________ twice. The rays of light have been drawn in the figures. Draw all the normals.



D-114

In the drawing, the sine of the angle of refraction could be found by computing $\frac{CD}{BD}$. The proportion between the side opposite the angle of ________, divided by the hypotenuse (or, side [\$]) is called the ________ of the angle of refraction.



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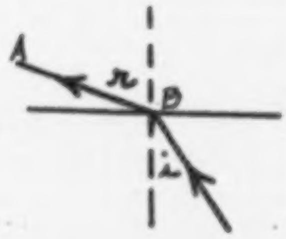
d-121

(Index of refraction =) $\frac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}}$

d-95

CB



d-69

2.5

d-43

vacuum, air, water, (glass), (diamond)

d-17

incidence

A·I·R ©1960

d-10

incident
reflected

d-36

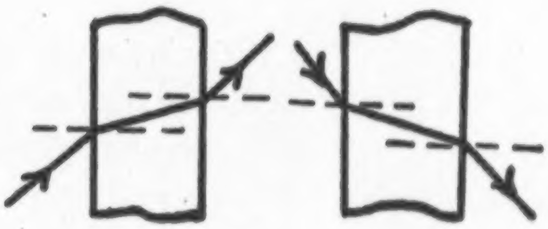
B (to) A

d-62

index of refraction

d-88

bent (or, refracted)



d-114

refraction
BD
sine

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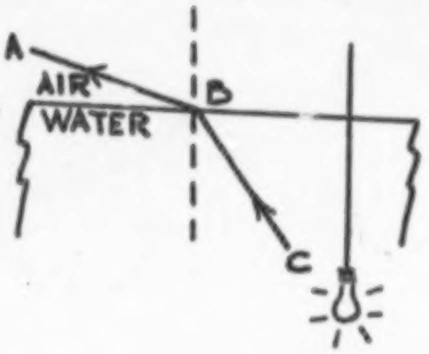
D-121

An important formula for finding the index of refraction is $\mu = \frac{\sin i}{\sin r}$. In words, this formula would read: Index of refraction = $\frac{\boxed{*\qquad\qquad}}{\boxed{*\qquad\qquad}}$

D-95



In the drawing below, light travels from a medium of low light velocity to a medium of high light velocity. In this case, the incident ray is line $\boxed{\$\quad}$. Add the letter "i" to show the angle of incidence, and the letter "r" to identify the angle of refraction in this drawing.

D-69

Sometimes, when we divide, the numbers do not come out even. Six divided by four is $\frac{6}{4} = 4\overline{)6}^{\,1.5}$. The calculations in the box show how we get 1.5 as the answer. What is 20 divided by 8? $\boxed{\#\quad}$.

$$\begin{array}{r} 1.5 \\ 4\,\overline{)6.0} \\ \underline{4} \\ 2\,0 \\ \underline{2\,0} \end{array}$$

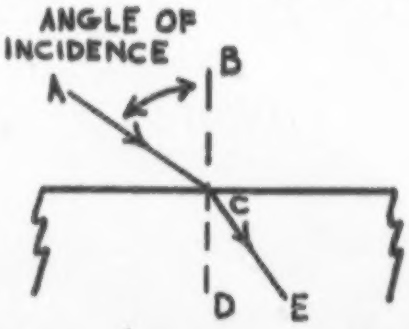
D-43

Light travels through water, diamond, glass, air or a vacuum. These media can be put in order according to the velocity of light through them. In the table below, the speed of light in diamond is less than light's speed in glass. Finish the table.

HIGHEST SPEED OF LIGHT				glass	diamond	LOWEST SPEED OF LIGHT

D-17

The diagram shows an incident ray striking a surface. To find the angle at which it strikes, called the angle of incidence, we must construct a normal, an imaginary line perpendicular to the surface at the point where the light touches. As shown in this drawing, lines BC and AC form the angle of $\boxed{\qquad\qquad}$.



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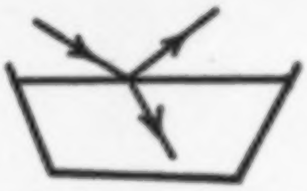
D-11

Part of a ray of light striking the surface of a pan of water is reflected. Part enters the medium and is refracted. The incoming light is called the incident ray, the light which bounces off the surface is the ______ ray, and the part which enters the water is the ______ ray.



D-37

Light travels at different speeds in different media. The velocity or ______ of light is greatest in a vacuum. Light can never travel faster than it does in a ______.

D-63

Complete the formula for the index of refraction for diamond:

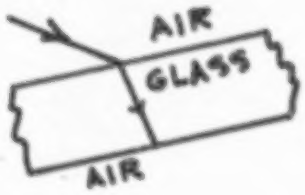
* ______ in a vacuum

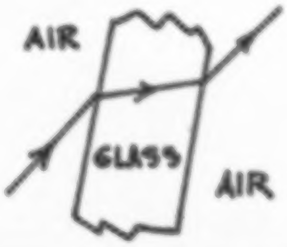
* ______ in a ______

= index of refraction for diamond.

D-89

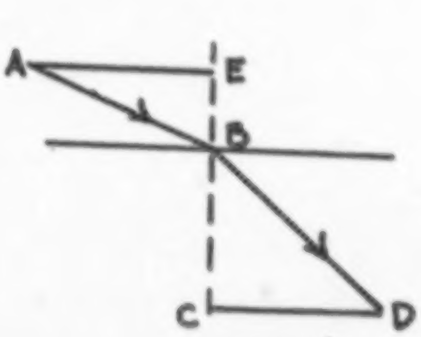
Draw the normals and path of light as it travels through these pieces of glass. Remember, light is bent toward the normal as it goes from air to glass and away from the normal as it goes from glass to air.





D-115

In this figure, the proportion $\frac{CD}{BD}$ is the sine of the angle of refraction. In the same way, a proportion using the side opposite the angle of incidence (AE) and hypotenuse (AB) would be the ______ of the angle of ______.



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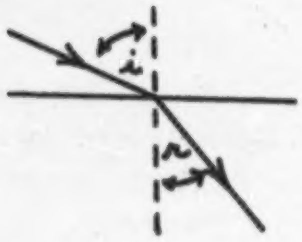
d-120

sin i

d-94



d-68

3

d-42

slower
faster

d-16

normal

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d-11

reflected
refracted

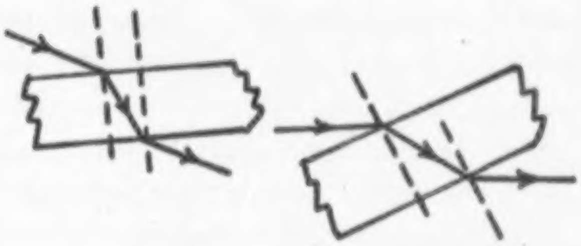
d-37

speed
vacuum

d-63

$\frac{\text{speed of light (in a vacuum)}}{\text{speed of light (in a) diamond}}$ (= index of refraction for diamond)

d-89



d-115

sine
incidence

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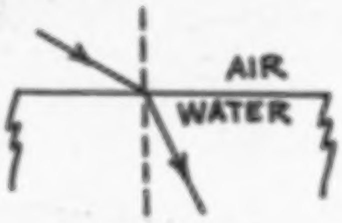
D-120

We can write the sine of the angle of refraction as "sin r." Using the abbreviation for sine and "i" for incidence, write in symbols "the sine of the angle of incidence." __________.

D-94

For any combination of media, each angle of incidence has a corresponding angle of refraction. We therefore have two angles which can be compared to each other to show the way light is bent as it passes across the boundary between them. In the drawing, put the letter "i" to identify the angle of incidence and the letter "r" to identify the angle of refraction.



D-68

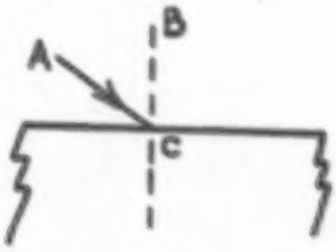
$\frac{21,600}{7,200} = \frac{216}{72}$. Now, divide 216 by 72. $72\overline{)216}$ __________

D-42

The speed of light in a diamond will be (faster/slower) __________ than it is in glass. We also know that the speed of light traveling in a vacuum will be (faster/slower) __________ than the velocity of light in either a diamond or in glass.

D-16

The diagram shows an incident ray striking a surface. To find the angle at which it strikes, called the angle of incidence, we must construct a normal, an imaginary line perpendicular to the surface at the point where light touches. In the drawing, line AC is the incident ray, line BC is the __________.



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㊾

D-12

The change of direction as light strikes a mirror is called ☐. The change of direction of light as it travels from air into glass is called ☐.

D-38

Light travels faster; that is, has a greater velocity, in a vacuum than it does in air. The velocity of light is greater in a ☐ than in ☐. The ☐ or speed of light is also greater in a ☐ than in glass.

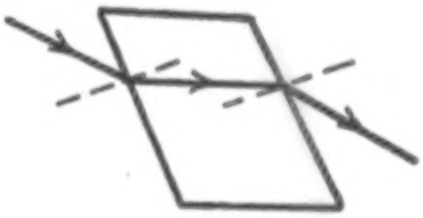
D-64

We use the letter "v" as a symbol for the velocity or speed of light. v_1 stands for light's velocity in a vacuum, and v_2 for the velocity of light in another medium.

Using symbols, the formula for the index of refraction is $\frac{\boxed{\$\quad}}{\boxed{\$\quad}}$ = index of refraction.

D-90

The drawing below shows the path of light in a particular shape of glass. This still illustrates our principle that light is bent ☐ the normal as it travels from a medium of high light velocity into a medium of lower light velocity, and bent again, this time ☐ * when the light returns to the medium of ☐ light velocity.



D-116

We can find the sine of the angle of incidence and of the angle of refraction. In either case, the formula $\frac{\text{opposite side}}{\text{hypotenuse}}$ is the formula for the ☐ of the angle.

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d-119

sin r

d-93

faster (or, greater) (slower)
slower (or, less) (faster)
bend

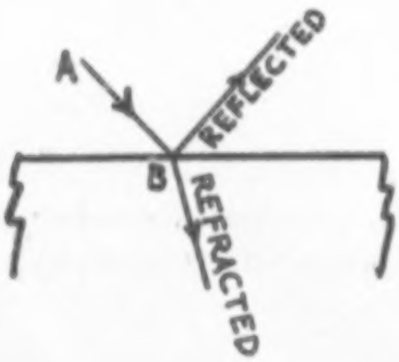
d-67

$\frac{216}{72}$

d-41

vacuum
velocity
less

d-15


A
B
REFLECTED
REFRACTED

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d-12

reflection
refraction

d-38

vacuum
air
velocity
vacuum

d-64

$\frac{v_1}{v_2}$

d-90

toward
away from the normal
higher (or, greater)

d-116

sine

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L

D-119

For convenience, we often use "sin" for "sine," "i" for incident and "r" for refracted. We then can write "sine of the angle of incidence" as sin i, and the "sine of the angle of refraction" in symbols as [$].

D-93

As light crosses the boundary between two media, changes in velocity (or speed) and in direction take place. The word "refraction" tells us the velocity of light will become either [ ] or [ ], depending on the index of refraction of each of the two media, and that light will [ ] toward or away from the normal, depending on the medium.

D-67

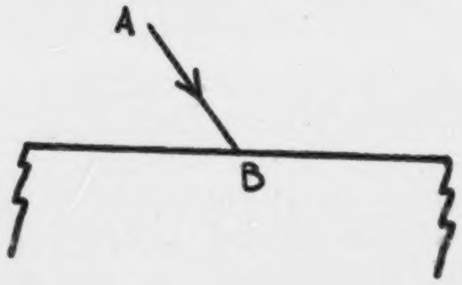
To compute the index of refraction when the velocity of light in the medium is known, we must divide one large number by another. This is really not very hard. For instance, to divide 21,600 by 7,200, write it as $\frac{21,600}{7,200}$. If we cancel zeros, we get $\frac{\boxed{\#\quad}}{\boxed{\#\quad}}$.

D-41

Light travels fastest in a [ ], but it travels faster in air, water or glass than it does in a diamond. The [ ] or speed of light in a diamond is (greater/less) [ ] than it is in glass.

D-15

In the figure, line AB has been drawn to show the incident ray of light striking a thick piece of plate glass. Complete the diagram to show both a reflected ray and a refracted ray. Label each.



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7

D-13

If we look through the plate glass window in front of a store, we sometimes can see the merchandise on the shelves, and, at the same time, a dim image of ourselves in the glass window. Seeing our own image is due to $\boxed{\quad\quad}$, but since some of the light has traveled from air through the glass, we know that $\boxed{\quad\quad}$ has also occurred.

D-39

Light travels faster in air than it does in water. In other words, the $\boxed{\quad\quad}$ or speed of light is greater in air than $\boxed{\quad\quad}$.

D-65

The index of refraction is written in symbol form as the Greek letter μ (pronounced "mew"). The formula $\frac{v_1}{v_2}$ = index of refraction could be written all in symbols as

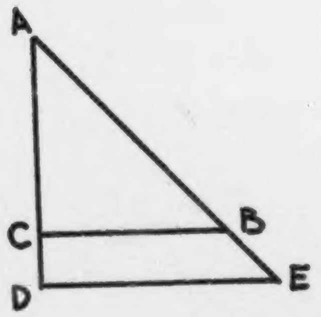
$$\frac{\boxed{\$\quad}}{\boxed{\$\quad}} = \boxed{\$\quad}$$

D-91

We already know that comparing the velocities of light in the formula $\frac{v_1}{v_2}$, is one way to find μ, or the $\boxed{*\quad\quad\quad\quad}$.

D-117

In order to find the sine of any angle, we use the proportion $\frac{\text{opposite side}}{\text{hypotenuse}}$ in a right triangle. The word "proportion" is important here, as we can see in the figure. The proportion $\frac{CB}{BA}$ is the same as the proportion $\frac{DE}{AE}$, either will give us the $\boxed{\quad\quad}$ of the angle A.



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d-118

same

d-92

index of refraction

d-66

velocity (or, speed)
vacuum
velocity of light
(refractive) medium
index of refraction (of the medium)

d-40

velocity (or, speed)
glass (water)
water (glass)

d-14

incident

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d-13

reflection
refraction

d-39

velocity
water

d-65

$\frac{v_1}{v_2} = \mu$

d-91

index of refraction

d-117

sine

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D-118

The sine for a given size of angle is always the ☐. We can find the value of the sine of any angle by looking it up in a table.

D-92

We found that it would be possible to calculate the index of refraction on the basis of light's velocity in different media. Actually, however, we calculate the ☐ * in terms of the angle of bending, since we know that light bends differently in different media.

D-66

In the formula $\mu = \frac{v_1}{v_2}$, v_1 represents the ☐ of light in a ☐, v_2 represents the ☐ * in any other ☐, and μ is the ☐ *.

D-40

Light travels still slower in glass than it does in air or water. The ☐ of light is greater in air than it is in either ☐ or ☐.

D-14

In our study of mirrors, we used the term incident ray to identify a beam which traveled from the light source to the surface. In refraction, the same term applies. Incoming light rays are called ☐ rays in the study of either reflected or refracted light.

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57
X

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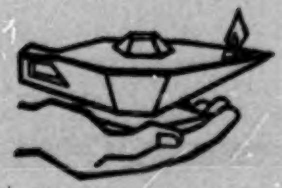
UNIT TWO

SNELL'S LAW, TOTAL REFLECTION, PRISMS

Steps D-129 through D-244



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UNIT ENDS HERE

(61)

D-129

A light source placed at the left as in Fig. 1, will send a light beam through a glass block in the manner shown. In Fig. 2, we have reversed the position of the [ ], causing light to travel from right to left.

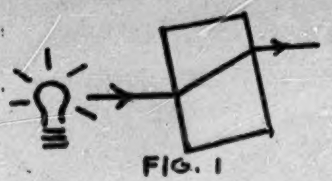


FIG. 1

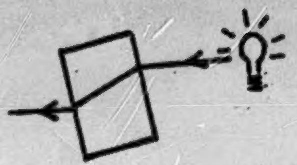


FIG. 2

D-153

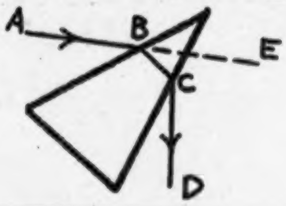
We know on the basis of [ ] Law that $\frac{\sin i}{\sin r}$ = [$]; that is, there is a fixed proportion, for any two media, between the angle of incidence and the angle of [ ]. The size or the thickness of any given material does not affect the amount which light is [ ] as it crosses the boundary between the media.

D-177

We can move our source of light within a medium such as water until refraction no longer occurs. When the light does not escape from its original medium, it is [ ] from the underside of the surface of the medium. This is called total reflection. Since the light does not go from one medium to another, no refraction occurs when [*] takes place.

D-201

Line ABE shows the path a light beam would take if refraction had not occurred. This theoretical line is a useful way of showing the deviation or amount which refraction has changed the path of incident light. Actually, we know that two seperate deviations occurred. Lines BC and [$] both show bending from the original path.



D-225

If the sine of the angle of incidence were .780 and the sine of the angle of refraction were .260, then, using Snell's Law, μ = [$].

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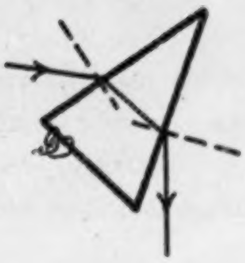
d-224

$$\mu = \frac{\sin i}{\sin r}$$

the index of refraction is equal to the sine of the angle of incidence divided by the sine of the angle of refraction.

d-200



d-176

reflected

d-152

angle of refraction

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d-129

source of light (or, light source)

---

d-153

Snell's

μ

refraction

bent

---

d-177

reflected

total reflection

---

d-201

CD

---

d-225

(μ =) 3.0

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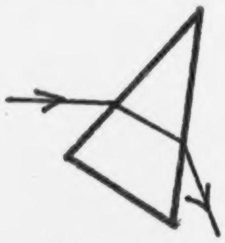
D-224

The Snell's Law formula is $. In words, it is expressed as **

.

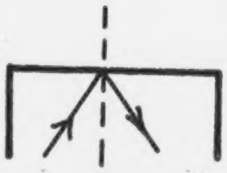
D-200

Draw in the two normals, where the light bends as it travels from air to glass and then where it changes direction again going from glass back into air.



D-176

By increasing the angle of incidence of light traveling from a medium which has a higher μ toward one which has a lower μ, we reach a point at which the light no longer leaves the medium with the high μ. This light is no longer refracted or bent, because it does not enter the second medium. Instead, it bounces from the surface while continuing to travel in one medium, which is the definition of light.



D-152

We can apply Snell's Law, $\frac{\sin i}{\sin r} = \mu$, to any pair of refractive media. "μ" will always be the same for any particular pair because a fixed proportion exists for any given transparent medium between the angle of incidence and the * .

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D-130

The principle of the reversibility of light rays is that, if the source of light were reversed, the beam of light would retrace the same path as before. A path of light is shown in Fig. 1. In Fig. 2, the source of light is reversed. Show the path of light for Fig. 2.

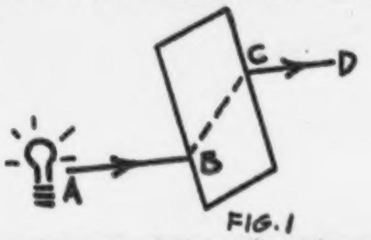


FIG. 1

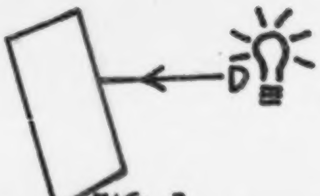


FIG. 2

D-154

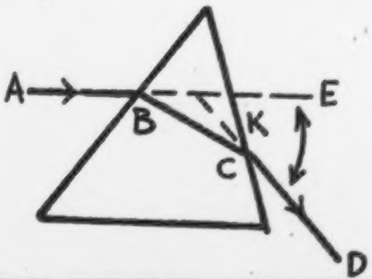
The line perpendicular to the surface at the point where a light ray strikes is called a [ ]. If a ray of light traveling from one medium to another is perpendicular to the boundary (or surface), the incident ray coincides with the [ ].

D-178

If we increase the angle of incidence of light originating in a medium with a high μ as when light travels from water to air, we reach a point where no light is refracted. It will all be [**]. This is a special case known as [*].

D-202

In optical usage, deviation refers to the amount of bending that occurs when light passes through a prism. The total amount of bending is the angle of deviation. In the drawing, angle K is called the [*] for this particular prism.

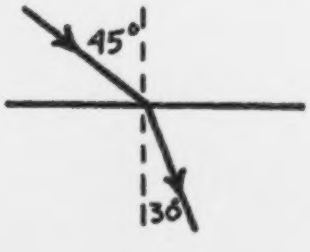


D-226

The figure shows the refraction of light. Using the sines given in the table, compute μ.

$$\mu = \frac{\sin i}{\sin r} = \frac{\#}{\#} = \#.$$

angle	sine
25°	.42
30°	.50
35°	.57
40°	.64
45°	.70



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d-223

incidence
refraction
$\mu = \frac{\sin i}{\sin r}$
Snell's Law

d-199

toward
away

d-175

water

d-151

would not

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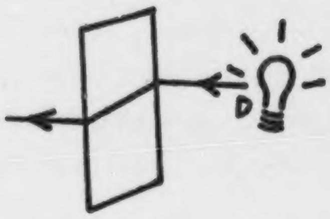
d-130



d-154

normal
normal

d-178

reflected within the medium
total reflection

d-202

angle of deviation

d-226

$(\mu=)\ \frac{.70}{.50} = 1.2$

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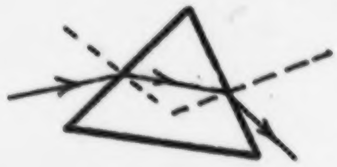
D-223

Using sin i and sin r for the sines of the angles of ______ and ______, write the formula for μ in terms of the amount light is bent. μ = $ ______ . This formula is known as * ______ .

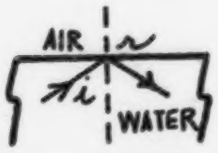
D-199

When light travels in a prism, the incident beam is first bent ______ the normal The same light beam, leaving the prism, is then refracted again as it enters the air, but now the beam is bent ______ from the normal.



D-175

If the light is traveling from water to air, and we keep increasing the angle of incidence, the angle of refraction will finally be so great that no light escapes into the air; the beam continues to travel in the ______.



D-151

We know that light bends as it travels between media of different index of refraction. Suppose we fastened together two media of equal index of refraction (two blocks of glass, for example) so that light traveled from one to another without touching any other medium between the two blocks. Light (would/would not) ______ be bent as it passed the surface into the second block of glass.

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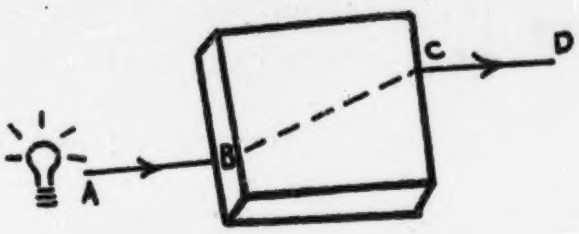
(69)

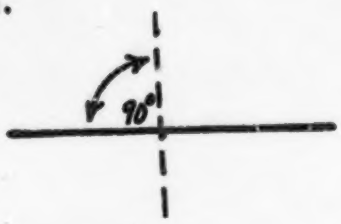
D-131

The diagram shows the refraction of light through a glass block and out into air again from A to B to C to D. The principle of the reversibility of light is illustrated if you move the light source to point [ ]. Now the beam will travel from point [ ] to [ ] to [ ] to [ ].



D-155

A line drawn perpendicular to a surface is one which forms a 90° angle with the surface. A normal is a line which is [ ] to a surface.



D-179

In Figure 1, light travels from water to air. This is an example of [ ] light. Figure 2 shows a large enough change in the angle of incidence to cause [*].

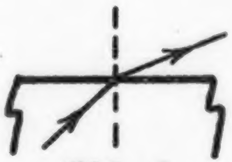


FIG. 1

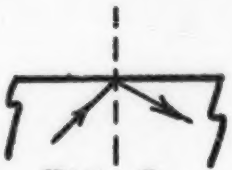


FIG. 2

D-203

Prisms can be made in special shapes to accomplish special purposes. One of these special shapes is called a right angle prism. This is a prism which includes one [*].

D-227

Air has a low index of refraction, near 1.0. Light entering air from a vacuum will change speed slightly and be bent to some extent. A diamond has an index of refraction of 2.4. This higher number of this index tells us that light entering a diamond from a vacuum will change speed and be bent to a (greater/less) [ ] degree than it would be entering air.

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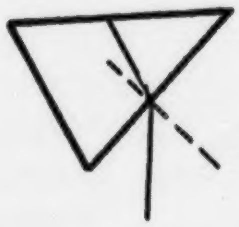
d-222

index of refraction
incidence
refraction

d-198



d-174

increases

d-150

the same

A·I·R ©1960

(71)

d-131

D
D (to) C (to) B (to) A

d-155

perpendicular

d-179

refracted
total reflection

d-203

right angle

d-227

greater

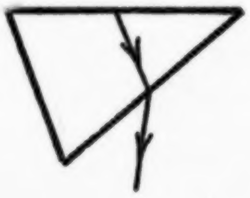
A·I·R ©1960

D-222

Light is bent as it crosses the boundary between two different media. By measuring the degree to which light is bent, we can also find the index of refraction. Knowing either how much light is bent, or how much it changes speed, will give us a proportion called the [*]. The Snell's Law formula uses the sine of the angle of [ ] and the sine of the angle of [ ] to find μ.

D-198

The figure shows a light beam traveling through a prism, and changing direction as it is refracted at the boundary into the medium with the smaller μ. Draw in the normal for this figure.



D-174

When light travels from water to air (higher μ to lower μ), the angle of refraction is larger than the angle of incidence, as in Figure 1. As the angle of incidence increases, the angle of refraction also [ ], as in Figure 2.

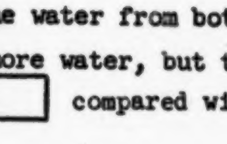


FIG. 1

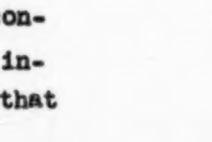


FIG. 2

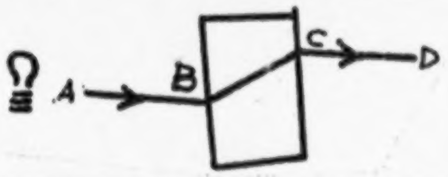
D-150

Suppose we have two containers filled with water and poured the water from both containers into a larger tank. The bigger container of course contains more water, but the index of refraction of the mixture is (different/the same) [ ] compared with that in either original container.

A·I·R ©1960

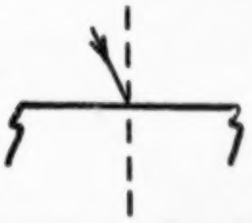
D-132

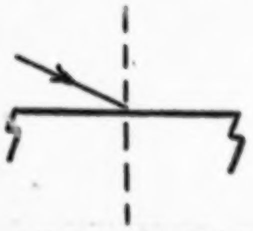
The fact that light will exactly retrace its path through any medium if the ray is reversed is known as the principle of ____ of light rays. If the light source in the figure were moved to D, line CD would then represent the ____ ray.



D-156

An incident ray which coincides with the normal, enters the medium at zero degrees angle of incidence because we measure the angle of incidence starting at the normal. An incident angle of ten degrees is close to the ____, and an incident ray of 80 degrees is farther away from the ____. Mark "10°" and "80°" in the proper angles below.





D-180

The angle at which light travels in a medium with a high μ may be great enough to keep the beam from refracting into another medium of lower μ. When light strikes the surface, but continues to travel in the medium with a high μ, we say that ____ * ____ has occurred.

D-204

Fig. 1 shows a right angle prism. Light beams entering one side along a normal will strike the far side at an angle of 45°, which is above the critical angle (42°) for glass. In this special case, no light will pass through the far side of the prism. Total ____ takes place and the light follows the path shown in Fig. 2.

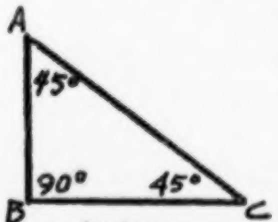


FIG. 1

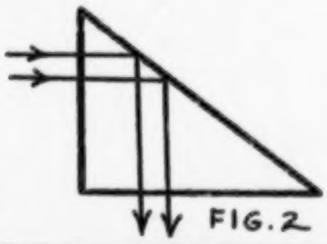


FIG. 2

D-228

When a light beam travels from one optical medium to a different medium, two things happen:

(1) There will be a change in light's ____.
(2) There will be a change in light's ____.

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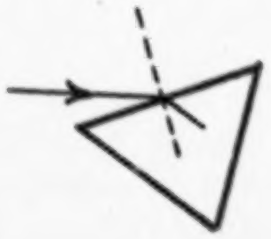
END OF UNIT

d-221

index of refraction
glass

d-197



d-173

larger
angle of incidence

d-149

toward or nearer
away
normal

A·I·R ©1960

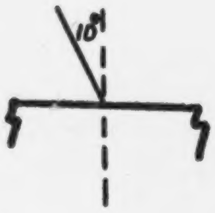
d-132

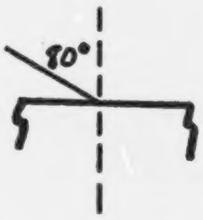
reversibility
incident

---

d-156

normal
normal





---

d-180

total reflection

---

d-204

reflection

---

d-228

velocity (or, speed)
direction

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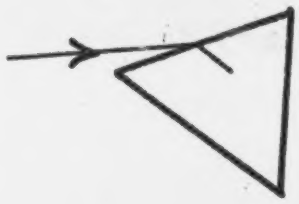
END OF UNIT

D-221

Using the speed of light in a vacuum (186,000 mi/sec) and the speed of light in glass (124,000 mi/sec), we could make a ratio or index $\frac{186,000}{124,000} = \frac{186}{124} = 1.5$ which would give us the * ______________ for ______.

D-197

The figure shows an incident ray and the change of direction as light refracts in a prism. Draw in the normal, perpendicular to the surface where the light enters.



D-173

As light travels from a medium of higher μ to one which has a lower index of refraction, the angle of refraction must be (larger/smaller) ______ than the * ______ ______________.

D-149

Light traveling from a medium of high light velocity into a medium of low light velocity is refracted or bent ______ the normal; but if the light went from a medium of low light velocity to one of high light velocity, it will bend ______ from the ______________.

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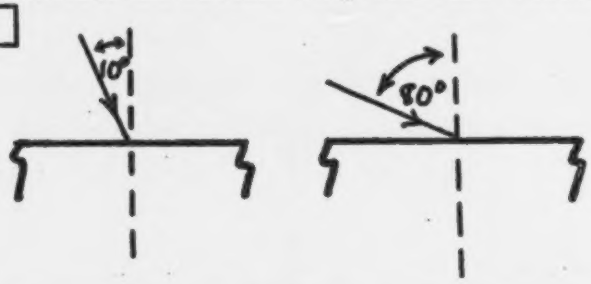
D-133

So far, the index of refraction has been described in two ways, $\mu = \frac{v_1}{v_2}$ and $\mu =$ $ ______. The first formula compares the velocity of light in some substance with the velocity of light in a ______. The second formula compares the angle made by a light ray with the normal before and after it crosses a ______ between two substances.

D-157

An incident angle of 10° is close to the normal and farther away from the surface; an incident ray of 80° is close to the ______ and farther away from the ______.

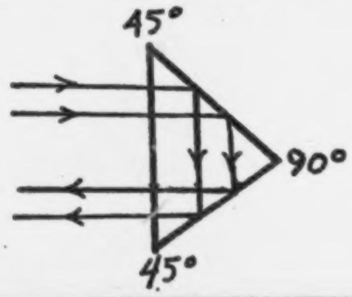


D-181

The angle of incidence which is just large enough to cause total reflection is called the critical angle; that is, light traveling toward a medium which has a lower index of refraction will cease to be refracted at one particular angle. Light will be totally ______ when the angle of incidence is as large as, or larger, than the ______ angle.

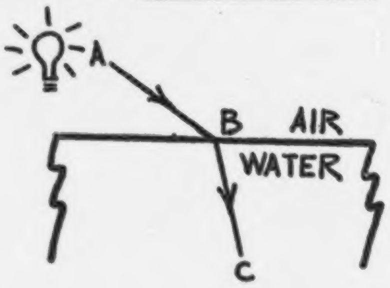
D-205

The drawing below shows a right angle prism placed so that the rays enter along a normal. In the special case illustrated, * ______ takes place twice within the prism.



D-229

A light ray which travels to the surface of a medium is called the ______ ray. After it crosses the boundary into a second medium, it is called the ______ ray. In the drawing, the arrows show the direction of the light ray. AB is the ______ ray. Line BC is the ______ ray.



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d-244

away

away from the normal

d-220

index of refraction is equal to the speed of light in a vacuum divided by the speed of light in any other medium.

d-196

toward

away

d-172

The light is bent toward the normal.

The angle of refraction is always smaller than the angle of incidence. (or, the angle of incidence is always larger than the angle of refraction.)

d-148

more

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79

d-133

$\frac{\sin i}{\sin r}$

vacuum

boundary

d-157

surface

normal

d-181

reflected

critical

d-205

total reflection

d-229

incident

refracted

incident

refracted

A·I·R ©1960

D-244

When light goes from a medium of low light velocity to one of high light velocity, light will be refracted ☐ from the normal. When light goes from glass to air, it will be bent [*].

D-220

One formula for index of refraction is $\mu = \frac{v_1}{v_2}$. In words, this formula means, [**].

D-196

In Figure 1, the beam AB, enters the medium of the prism from air. It is bent ☐ the normal. In Figure 2, the beam leaves the prism and enters the air. At point C, beam CD was bent ☐ from the normal.

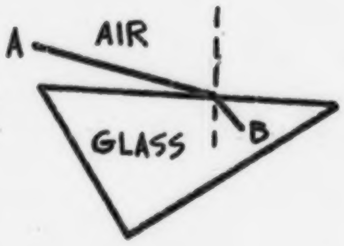

FIG. 1

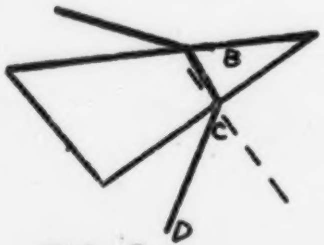

FIG. 2

D-172

Describe what happens when a light ray goes from a medium which has a low index of refraction to one in which the μ is higher. [**]. What is the relationship between the size of the angle of incidence of this beam and the size of the angle of refraction? [**].

D-148

The index of refraction for diamond is greater than the μ of glass. Light traveling from air to diamond will, by comparison, bend (more/less) ☐ than light traveling from air to glass.

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D-134

The formula $\mu = \frac{\sin i}{\sin r}$ will give the same index of refraction for a substance as the formula $\mu =$ [$] only when we compare the sines of the angles of incidence and [ ] as the ray of light enters a substance from (or leaves it going into) a vacuum. If we were to use another substance as the standard, such as water, μ would be (the same/different) [ ].

D-158

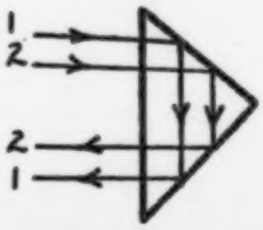
The incident ray and the normal coincide when the incident ray is [**]. In this case, the angle of incidence would be [ ] degrees, because we measure the angle beginning at the [ ].

D-182

The specific angle of incidence at which total reflection begins is called the [*]. Refraction will occur when the angle of incidence is smaller than the [*].

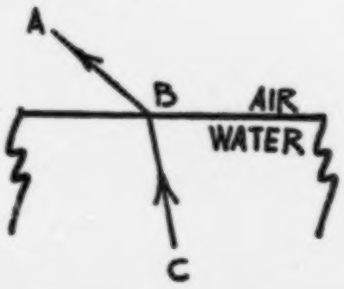
D-206

Prism binoculars make use of the principle of total reflection of light. The drawing below is an example of a prism which might be used in binoculars. It shows the [*] of light beam occurring twice in the prism.



D-230

The figure shows a light beam beginning in water and refracted into air. In this case, the incident ray is line [$] and AB is the [*].



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d-243

low
high

d-219

μ

$\mu = \frac{v_1}{v_2}$

d-195

toward
away

d-171

away from the normal
smaller

d-147

index

A·I·R ©1960

83

d-134

$\frac{v_1}{v_2}$

refraction

different

d-158

perpendicular to the surface

zero

normal

d-182

critical angle

critical angle

d-206

total reflection

d-230

BC

refracted ray

A·I·R ©1960

D-243

When light goes from water to air, it goes from a medium of (high/low) ☐ light velocity to one with (high/low) ☐ light velocity.

D-219

The index of refraction is abbreviated [$]. Using v_1 for the velocity of light in a vacuum and v_2 for the velocity of light in any other medium, write the formula for index of refraction in symbols. [$].

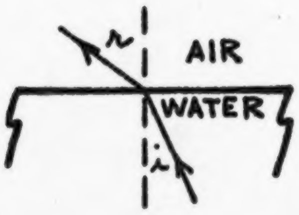
D-195

Light traveling through a prism bends twice. It is bent as it goes from air to the glass; it bends again as it crosses the boundary back into air. As you learned, the beam bends ☐ the normal as it enters the glass, and then ☐ from the normal as it returns to air.

D-171

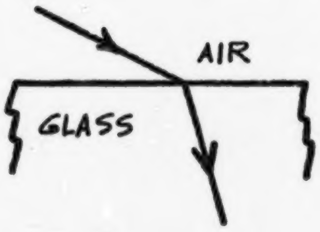
As light goes from a medium of low light velocity to one of higher light velocity, it bends [*].

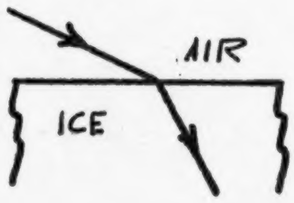
Therefore, as light travels from water to air, the angle of incidence must always be (larger/smaller) ☐ than the angle of refraction.



D-147

Light going from air into glass is bent more than light traveling from air to ice. We could say that glass has a higher ☐ of refraction than ice.





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D-135

If we used water instead of a ______ as the standard for finding μ or the * ______, v_1 in the formula $\mu = \frac{v_1}{v_2}$ would be the velocity of light in ______. Likewise, in the formula $\mu = \frac{\sin i}{\sin r}$, we would measure the path of light as it entered the medium from ______.

D-159

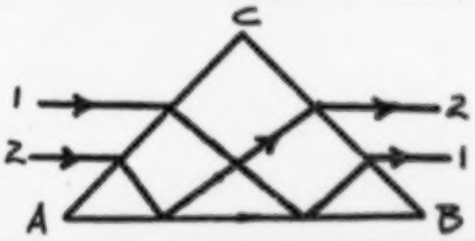
When light enters a medium perpendicular to the surface, light is not bent. The angle of incidence is ______ degrees.

D-183

'A beam of light usually bends as it travels from a medium of higher refractive index toward one which has a lower μ. If the angle of incidence becomes larger than the critical angle, * ______ takes place and the light does not enter the * ______.

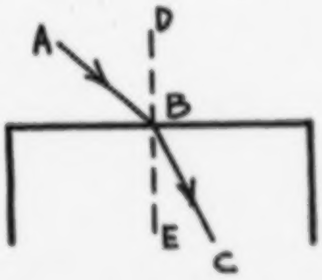
D-207

A special use for a right angle prism is diagrammed below. Note that each beam that strikes the surface CA, is bent or ______ to surface AB, where * ______ takes place. As the rays of light leave the prism at surface $ ______, they have switched positions; that is, they have been inverted.



D-231

An imaginary line drawn perpendicular to the surface of a medium is called a normal. In the drawing, point B is the spot at which light enters a block of glass and dotted line DBE is the ______.



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d-242

toward

toward the normal

d-218

index of refraction

d-194

glass

crosses the boundary from glass to air (or, goes back into air)

d-170

toward

larger

d-146

the bending and the change in velocity of light as it crosses the boundary between two different media.

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d-135

vacuum
index of refraction
water
water

d-159

zero

d-183

total reflection
second medium (or, medium of lower density)

d-207

refracted
total reflection
BC

d-231

normal

A·I·R ©1960

D-242

When light goes from a medium of high light velocity to one of low light velocity, light will be refracted ____ the normal. When light goes from air to glass, it will be bent * ____.

D-218

By setting up a proportion between the velocity of light in a vacuum and the velocity of light in a different medium, we can find the * ____ for ice, for diamond or for any other refractive medium.

D-194

We know that a beam of light is refracted twice when it goes from air through glass and back into air. The light is bent once as it crosses the boundary between air and ____ and once as it ** ____.

D-170

As light goes from a medium having a lower index of refraction to a medium with a higher μ, light is bent ____ the normal. Therefore, as light goes from air to water, the angle of incidence must always be (larger/smaller) ____ than the angle of refraction.

D-146

As light crosses the boundary between two different media; that is, as it goes from one medium to another, the light ray will change in its speed and direction. We define refraction as ** ____.

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D-136

When we use the term, index of refraction, for a particular medium, we generally mean the index of refraction based on using a ________ as the standard. Since air is very much like a ________, in practice we often use air as the standard instead.

D-160

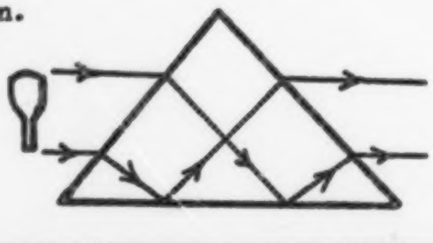
Snell's Law provides an explanation of the fact that light does not bend if the incident ray enters perpendicular to the surface of a medium. $\frac{\sin i}{\sin r}$ is a fixed proportion. If sin i is zero, as it is when the angle of incidence is zero, then sin r is also ________.

D-184

The index of refraction of a diamond is very high, and its critical angle is rather small (24°). As a result of the way it is cut, much of the light which enters a cut diamond is totally reflected at the bottom and will emerge from the top of the diamond. The brilliant appearance of a diamond is due to the combination of its high index of ________, and the amount of * ________ which takes place because of its low critical angle.

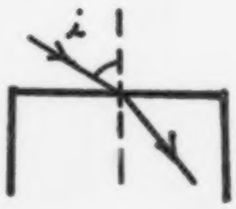
D-208

A prism such as Figure 1 inverts an image, or turns it upside down. If we started with an upside down image of a bottle, the use of an inverting prism would turn the image to an upright position. Draw the image of the bottle as it would appear after the light rays passed through the prism.



D-232

When we speak of the angle of incidence, we refer to the angle made by the incident ray and the imaginary normal line. In the drawing, angle "i" identifies the * ________.



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d-241

high
low

---

d-217

index of refraction

---

d-193

parallel
incident

---

d-169

perpendicular
increase angle of refraction
decrease the angle of refraction

---

d-145

medium
boundary

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(91)

d-136

vacuum
vacuum

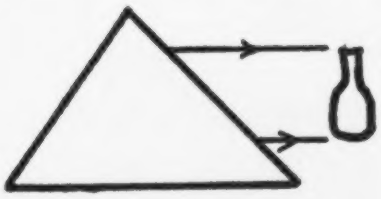
d-160

zero

d-184

refraction
total reflection

d-208



d-232

angle of incidence

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D-241

When light goes from air to water, it goes from a medium of (high/low) [ ] light velocity to one with (high/low) [ ] light velocity.

D-217

We can use the proportion $\frac{v_1}{v_2}$; that is, the velocity of light in a vacuum compared to the velocity of light in any other medium, to find μ , or the [*].

D-193

As it leaves a plane-parallel medium, the refracted ray is displaced laterally but comes out [ ] to the incident ray. As it leaves a prism, the refracted ray is not parallel to the [ ] ray.

D-169

Regardless of the direction of light, some bending always occurs as light travels between two media of different index of refraction unless the incident ray happens to be [ ] to the boundary. When bending does occur, increasing the angle of incidence will always [**]. Decreasing the angle of incidence will always [**].

D-145

Refraction occurs only when light goes from one medium to another [ ]. The bending occurs at the boundary between two media of different indices of refraction. Refraction, then, is the bending of light and the change in velocity of light as it crosses the [ ] between two media.

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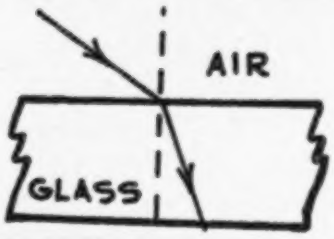
D-137

When light travels from a medium with a lower index of refraction to a medium which has a higher index of refraction, the light is bent so that the angle of ______ is smaller than the angle of ______.



D-161

When light goes from air to glass it is bent * ______. This is true except when the angle of incidence is zero degrees; that is, except when the incident ray of light is ______ to the surface.

D-185

A light beam traveling from a medium of low refractive index into one which has a higher index always has a larger angle of incidence than angle of refraction. If we increase this angle, we see that it will reach the surface sooner than the refracted ray. We can see that total reflection cannot occur if light travels from a medium of ______ refractive index to a medium of ______ refractive index.

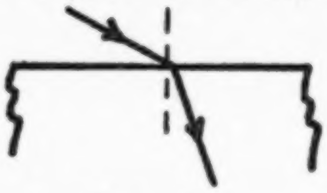


FIG. 1

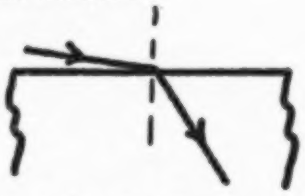


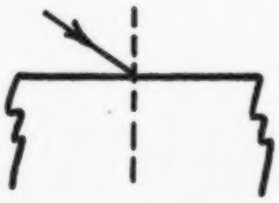
FIG. 2

D-209

The branch of physics which deals with the behavior of light is called optics. The nature of light seen through a telescope, or the appearance or image of goldfish swimming in a bowl are both examples of problems in ______.

D-233

Label the incident ray, the normal, and the angle of incidence in the drawing below.



A·I·R ©1960

d-240

slower
higher
lower

---

d-216

vacuum
velocity
slower (or, less)

---

d-192

parallel

---

d-168

larger

---

d-144

angle of incidence
angle of refraction
sin r
$(\mu =) \frac{\sin i}{\sin r}$

A·I·R ©1960

d-137

refraction
incidence

d-161

toward the normal
perpendicular

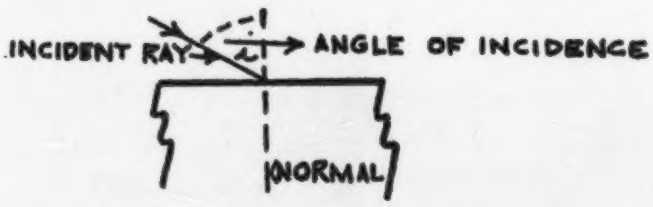
d-185

low
higher

d-209

optics

d-233


INCIDENT RAY
i
ANGLE OF INCIDENCE
NORMAL

A·I·R ©1960

D-240

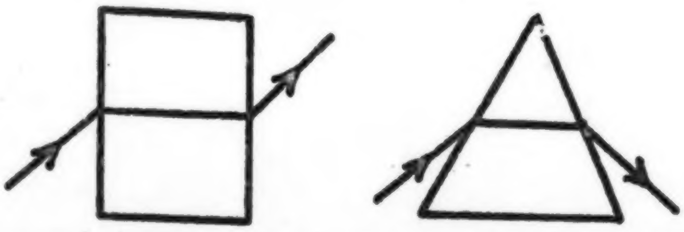
The higher the μ, the ____ light will travel as it passes through that medium. Glass and a diamond have ____ indices of refraction than water. Air and a vacuum have ____ indices of refraction than water.

D-216

Light travels fastest in a ____, but it travels faster in air, water or glass than it does in a diamond. The ____ or speed of light in a diamond is ____ than in glass.

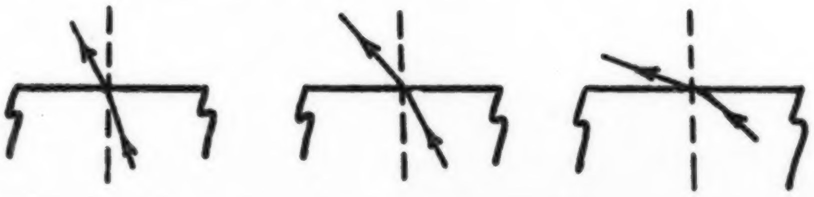
D-192

Light refracted through a plane-parallel shape is bent twice, and the outcoming beam will be parallel to the incident beam. Light traveling through a prism is also bent twice, but as it re-enters the air, the exit beam will no longer be ____ to the incident ray.



D-168

In the drawings, light travels from water into air. As the angle of incidence is made larger, the angle of refraction also becomes ____.



D-144

In order to compute the index of refraction using Snell's Law, you must know the sine of the * ____ and the sine of the * ____. To compute μ we divide sin i by $ ____. The formula for μ based on the sines of angles is = $ ____

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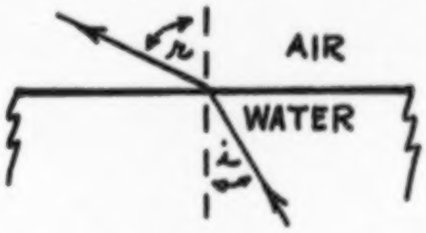
D-138

Because the path remains the same if a light ray is reversed, if light goes from a medium having a higher index of refraction to a medium having a lower index of refraction, the angle of incidence would be ________ than the angle of ________.



D-162

Light which strikes perpendicular to the boundary between two media is not bent, regardless of the index of ________ of either ________.

D-186

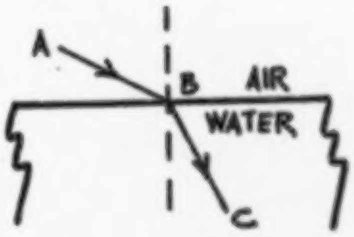
Total reflection can only occur when light travels from a medium which has a ________ index of refraction toward a medium which has a ________ index of refraction. It does not occur when light travels from a medium of lower refractive index into one which has a ________ refractive index.

D-210

In optics, a transparent substance in which light can travel is known as an optical ________. A diamond is an example of an optical ________.

D-234

In the drawing, line AB is the incident ray. At point B, the ray was refracted as it crossed the boundary into the second medium. The refracted ray in this diagram is shown by the letters $ ________.



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d-239

higher
higher

d-215

velocity
air
vacuum

d-191

lateral displacement

d-167

higher
lower

d-143

sin i
sin r
μ

A·I·R ©1960

d-138

smaller
refraction

d-162

refraction
medium

d-186

high
lower
higher

d-210

medium
medium

d-234

BC

A·I·R ©1960

D-239

A vacuum has a lower μ than water. Light has a (higher/lower) [ ] velocity in a vacuum than in water. The lower the index of refraction, the (higher/lower) [ ] the velocity of light in that medium.

D-215

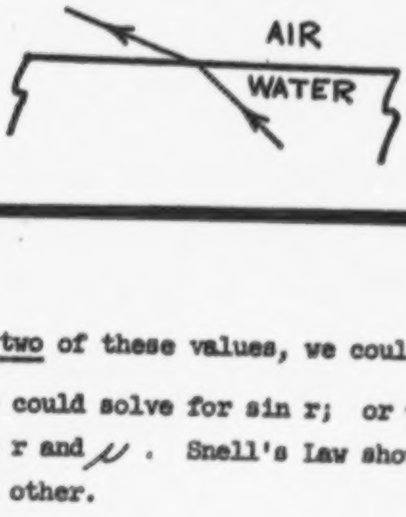
Light travels slower in water than it does in air. The [ ] or speed of light is less in water than in [ ] or a [ ].

D-191

Lateral displacement of light results from the use of a plane-parallel shaped refractive medium. A prism's sides are not parallel; [*] will not occur when a light ray passes through a prism.

D-167

When light travels from water into air, the incident ray is the path of light in the medium which has a [ ] index of refraction. The refracted ray travels in the medium which has a [ ] index of refraction.



D-143

Snell's Law is written as $\frac{\sin i}{\sin r} = \mu$. Knowing any two of these values, we could solve the problem for the third. Knowing sin i and μ, we could solve for sin r; or we could calculate the value of sin i if we know values for sin r and μ. Snell's Law shows us that [$], [$] and [$] are related to each other.

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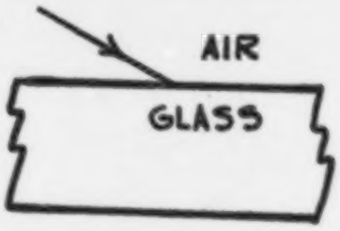
D-139

Draw in the normal and refracted ray in the diagram below. The refracted ray will bend * ____________.

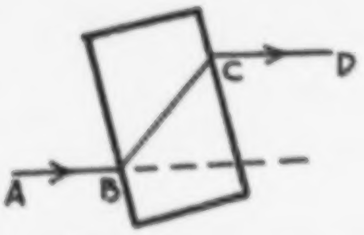


D-163

Snell's Law, $\mu = \frac{\sin i}{\sin r}$, tells us that an exact proportion must exist between any angle of incidence and its angle of refraction. This means that any time the angle of incidence is changed, there must also be a change in the * ____________.

D-187

The dictionary defines a lateral movement as a sideways movement. In the example, the entrance and exit rays of light beam ABCD are parallel, but CD is not in a straight line with AB. By refracting the beam, we have displaced the light beam in a sideways direction; the exit ray has a ____________ displacement.

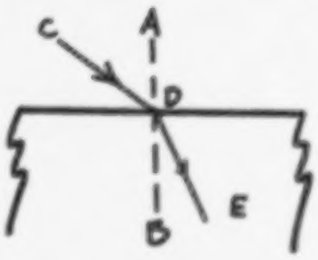


D-211

Any transparent substance is an * ____________. Some substances, such as coal, *do not permit the entry of light*, and cannot be classified as * ____________.

D-235

The angle between the normal and the path of the refracted beam is called the angle of refraction. In the drawing lines DB and DE form the * ____________ ____________.



A·I·R ©1960

d-238

refracted
normal

d-214

vacuum
air
velocity
vacuum

d-190

parallel

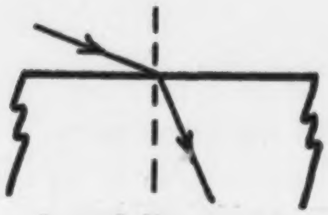
d-166

lower
higher

d-142

lower (or, smaller)

d-139



toward the normal

d-163

angle of refraction

d-187

lateral (or, sideways)

d-211

optical medium
optical media

d-235

angle of refraction

A·I·R ©1960

D-238

The angle of refraction is formed by the ☐ ray and the ☐.

D-214

Light travels faster; that is, has a higher velocity, in a vacuum than it does in air. The velocity of light is greater in a ☐ than in ☐. The ☐ or speed of light is also greater in a ☐ than in glass.

D-190

A plane-parallel (Fig. 1) is shaped so that its opposite sides are parallel. A prism (Fig. 2) has a base larger than its top. Its opposite sides are not ☐.

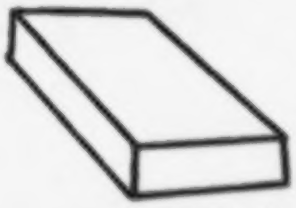


FIG. 1

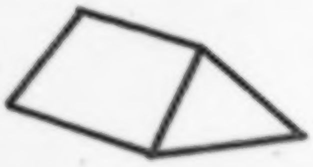


FIG. 2

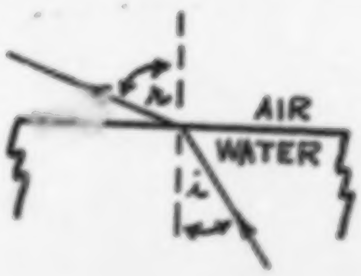
D-166

Light travels faster in media with low indices of refraction. When light travels from air to water, the incident ray first travels in the medium which has the (higher/lower) ☐ index of refraction. The refracted ray then travels in the medium which has the (higher/lower) ☐ index of refraction

---

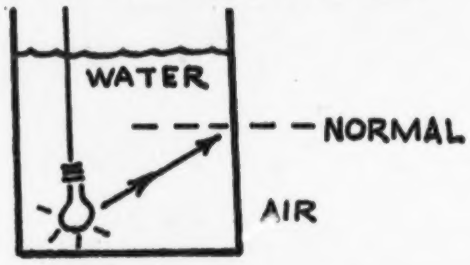
D-142

When the angle of incidence is smaller than the angle of refraction, we know the beam of light has traveled from a medium whose index of refraction is higher to a medium with a ☐ index of refraction.



D-140

Draw the refracted beam in the diagram below. (Hint: note how the normal is drawn). In this case, the refracted ray will bend * ________ ________.



D-164

In the figures, light is going from air to glass. In Fig. 1, the angle of incidence is 20 degrees; in Fig. 2, the angle of incidence is about 45 degrees; in Fig. 3, it is about 80 degrees. From these figures you can see that as the angle of incidence gets larger, the angle of refraction also gets ________.

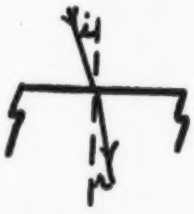


FIG. 1

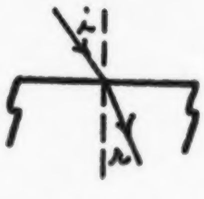


FIG. 2

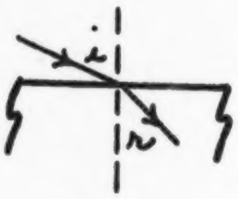
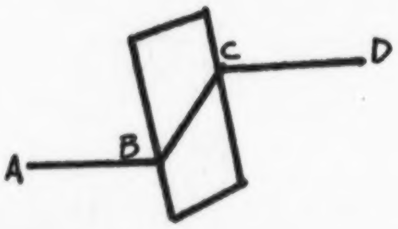


FIG. 3

D-188

The lateral displacement of a light beam refers to the path a beam takes after it has passed through a refractive medium. The exit ray parallels, but does not follow, the original course of the beam. Lines AB and $ ________ are parallel; they show * ________ ________ caused by refraction.

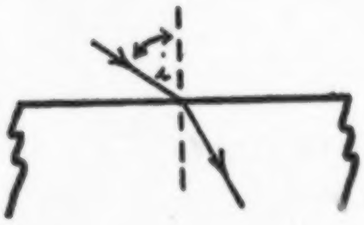


D-212

Refracted light is light that travels from one medium to another. As it crosses the boundary between the two media, its rate of travel (or velocity) changes and its direction changes. A beam of light traveling from air to diamond will be refracted; therefore, there will be changes in its ________ and ________ as the beam enters the second medium.

D-236

We measured the angle of incidence by using the normal and the incident ray, labeling it "i". The angle of refraction is formed by the normal and the refracted ray. Label the angle of refraction between these lines with the letter "r".



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d-237

incident (ray)
normal

d-213

vacuum

d-189

lateral displacement

d-165

is made larger

d-141

smaller (or, less)

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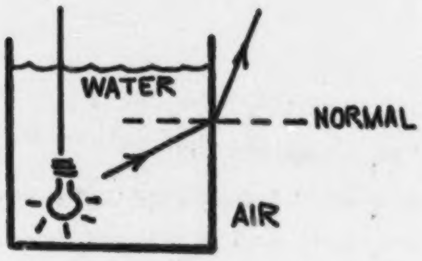
d-140


WATER
NORMAL
AIR

away from the normal

d-164

larger

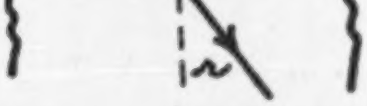
d-188

CD
lateral displacement

d-212

velocity (or speed)
direction

d-236



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D-237

The angle of incidence is formed by the ☐ ray and the ☐.

D-213

Light travels at different speeds in different media. The velocity of light is greatest in a vacuum. Light can never travel faster than it does in a ☐.

D-189

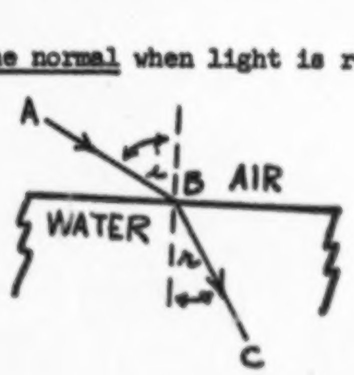
In order to cause lateral displacement of light, we use a block of transparent material of a special shape. A "plane-parallel" shape has parallel sides so that light enters and leaves the block at exactly the same angle. Any transparent medium with parallel sides will cause the sideways motion of refracted light which is called ☐ *.

D-165

As light goes from one medium into another, if the angle of incidence is made larger, the angle of refraction also ☐ *.

D-141

The figure shows the bending of light toward the normal when light is refracted as it enters a medium with a higher index of refraction. Here the angle of refraction would be ☐ than the angle of incidence.



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UNIT THREE

IMAGE FORMATION

Steps D-245 through D-349

BEGIN UNIT HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

UNIT ENDS HERE

D-245

Lenses are often made of glass because glass is hard, inexpensive, and has a high index of refraction. However, any dense, transparent material such as quartz, plastic or even ice could also be used to make a ______.

D-267

Rays from the sun strike a lens surface parallel to each other. Fig. 1 and Fig. 2 show the characteristic bending of light by different types of lenses. We can see that light rays which were originally parallel to each other have been bent differently. They are no longer ______.

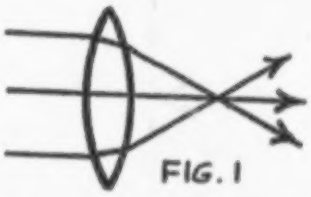


FIG. 1

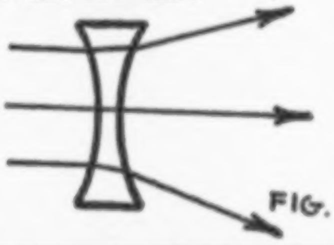
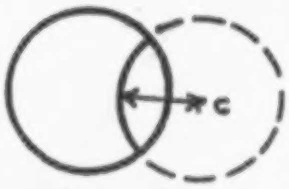


FIG. 2

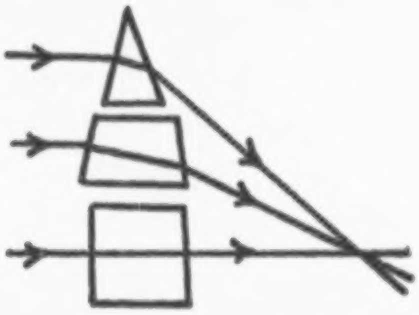
D-289

Since the curved surface of a lens face is part of the surface of a sphere, we can describe the lens in terms of a whole sphere's measurements. We can find the radius of the sphere; in the same way, we can find the ______ of the lens face which is part of the sphere's surface.



D-311

The beams leaving the three prisms indicated, are not parallel. The angles made by the sides of the prisms are different so the rays of light tend to come together or ______.



D-333

"Converging" is a general term for light traveling toward a point. Focused beams are converging beams which meet so as to form a sharp, clear image before they again diverge. A camera needs a lens which provides a sharp, clear image. The camera lens converges light rays so they are ______ at the film.

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d-332

nearer

d-310

deviation

d-288

the center of a sphere to any point on the sphere's surface

d-266

parallel

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d-245

lens

d-267

parallel

d-289

radius

d-311

converge

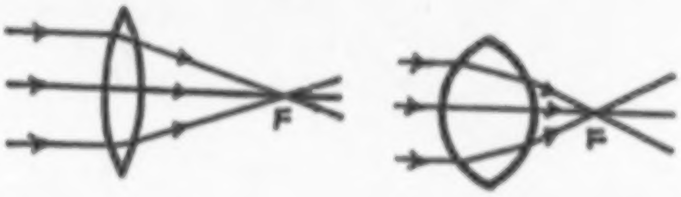
d-333

focused

A·I·R ©1960

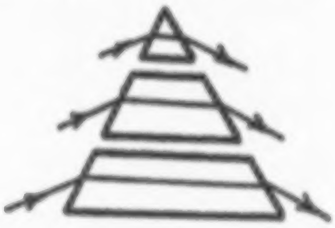
D-332

The principal focus of a small radius lens; that is, one which is sharply curved, will be (nearer/farther) ________ to the lens than the principal focus of a large radius lens which is less sharply curved.



D-310

In order to make three originally parallel light beams travel parallel to each other after leaving a prism, we could use three prisms which had sides forming identical angles. The light beams in the figure travel parallel after refraction; we know the prisms must have identical angles because the angles of ________ produced are the same.



D-288

We can measure the radius of a sphere in the same way that we measured it for a circle. The radius of a sphere is the distance from ** ________.

D-266

For our purposes, we think of the sun's rays as parallel because the source is so far away. Sunlight striking a lens is said to enter that lens in ________ rays.

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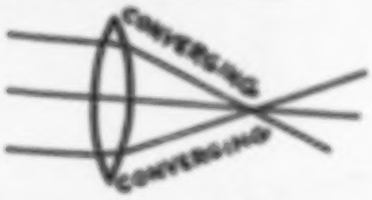
D-246

When we think of a lens, we usually visualize a manufactured article. Actually, any transparent medium with curved surfaces is a form of a ☐.

D-268

One type of lens bends the parallel rays of sunlight until they converge or come toward each other. Converging beams are an example of rays which are not ☐ to each other. They come together or meet.

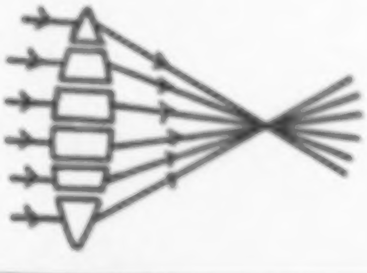


D-290

The point from which we measure the radius of a sphere is called the center of curvature. The radius of a lens face is measured from the ☐ of the imaginary sphere of which it is part.

D-312

By properly choosing a set of prisms, ones which had sides that formed different ☐, we can make parallel rays of light meet at a single point.



D-334

A focused image is sharp and clear. Sometimes a lens will produce a "fuzzy" image. The details are not clear or distinct. We say that the image has not been ☐ properly.

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d-331

near the lens (or, close to the lens)

d-309

angle

d-287

center
radius

d-265

parallel

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(119)

d-246

lens

d-268

parallel

d-290

center of curvature

d-312

angles

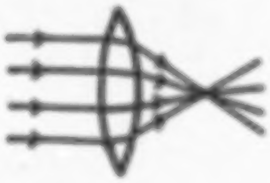
d-334

focused

A·I·R ©1960

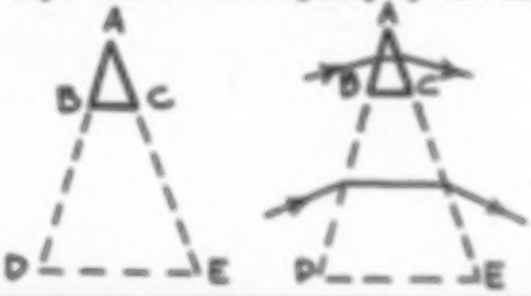
D-331

Some lenses have sharply curving sides. A spherical surface with a small radius bends light sharply. This means that the beams will converge so that the principal focus will be * ________.



D-309

Prism ABC has the same angle as prism ADE. The rays will be bent equally by the smaller or the larger prism. Neither the length of the sides nor the thickness of a prism affects the degree to which a given ray of light is bent, so long as the ________ made by the sides of the prism remains the same.



D-287

A ball is perfectly round; it is spherical. We know that we could draw the radius of a circle from its center to any point in the outer surface. A line connecting the ________ of a sphere with any point on the sphere's surface would be called a ________ of the sphere.

D-265

We know that parallel lines never meet, but remain at equal distances from each other. In optics, we speak of parallel light rays, meaning rays which travel in the same direction without touching. In the figure, these light rays are traveling ________ to each other.

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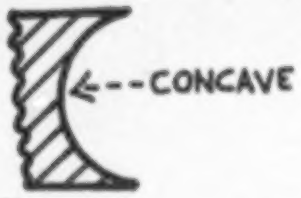
D-247

We learned during our study of mirrors that a concave mirror had a characteristic shape. A surface which has a round, hollowed-out design, such as the one in the figure, is called a ________ surface.

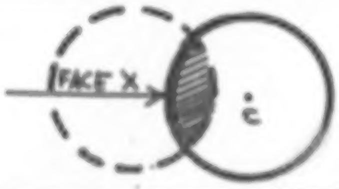


D-269

Lenses are commonly named for their shape, either convex or concave. In use, a convex lens acts as a converging lens, making parallel light beams meet. Either name can be used to describe this lens; a convex lens is also called a ________ lens.

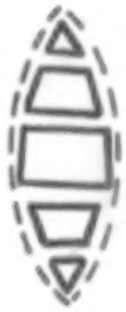
D-291

In the drawing, lens face X is shown as part of an imaginary sphere, the one drawn with a solid line. The center of curvature for any part of that sphere's surface is at point C, the center of the sphere. Point C is, therefore, the * ________ of lens face X. We measure the ________ of face X by a line drawn from point $ ________ to the surface of face X.



D-313

Lenses have curved surfaces. Light will be bent by curved surfaces as if the lens were made of several prisms stacked on each other. We can control the amount which light is ________ by any section of the lens by changing the curvature of a lens.



D-335

We use the term "focused" to mean that the image produced by a lens is ________.

A·I·R ©1960

d-330

principal focus (or, focal point)

d-308

sides
deviation

d-286

sphere

d-264

double convex

A·I·R ©1960

d-247

concave

d-269

converging

d-291

center of curvature

radius

C

d-313

bent (or, refracted)

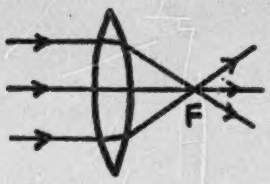
d-335

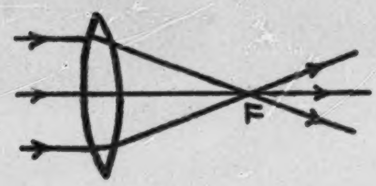
clear (or, sharp, distinct, not fuzzy)

A·I·R ©1960

D-330

A sharply curved convex lens bends light sharply so that parallel light rays converge close to the lens. We call this common point of convergence the * ____________ regardless of its distance from the lens.





D-308

If we took a prism (Figure 1) and cut off the top (Figure 2), we have not changed the angle of the sides. The angle of a prism's sides determines the degree of bending. Cutting off the top does not affect either the angle made by the ________ of the prism or the angle of ________.

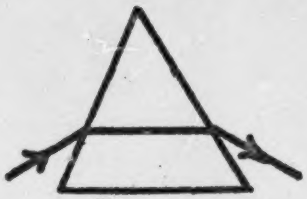


FIG. 1

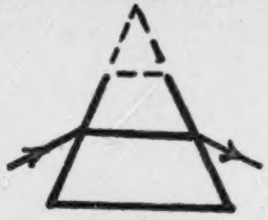


FIG. 2

D-286

A sphere (pronounced "sfeer") is any ball-shaped or perfectly round object. A marble, or even an orange, may be an example of a ________.

D-264

Judging by their shape, we could identify Figure A as a double concave lens. Figure B is a * ____________ lens.

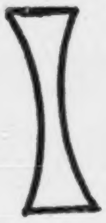


FIG. A

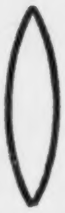


FIG. B

(121)

A·I·R ©1960

D-248

A lens has two surfaces through which light passes. Often, both sides of a lens are identical. Figure 1 shows a characteristic concave surface; the lens in Figure 2 has two identical ________ surfaces.

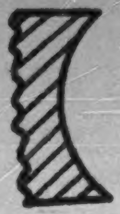


FIG. 1

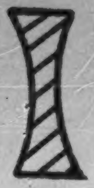
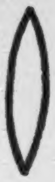


FIG. 2

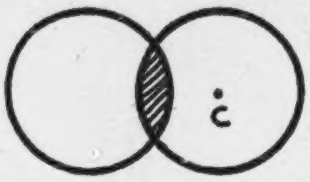
D-270

This lens is a double ________ lens, recognizable because of the shape of the surfaces. This shape of lens has a particular use in optics; it will make parallel light beams bend so that they ________.



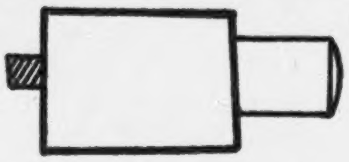
D-292

Point C, the center of an imaginary sphere, is used as the * ________ for the lens surface which is part of that sphere.



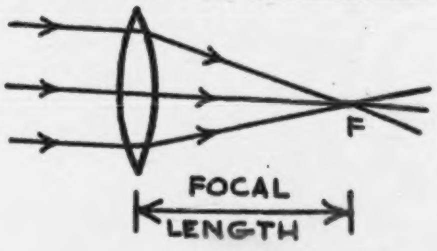
D-314

Because the sun is so far away, the rays of sunlight striking the earth are parallel to each other. Many artificial light sources are constructed so that they produce parallel rays of light. Draw in several parallel rays of light coming from this light source.



D-336

The distance from the principal focus to the center of the lens is called the focal length. If the principal focus is near the lens, we say the lens has a short focal length. If the principal focus is farther from the lens, we say the lens has a longer * ________.



A·I·R ©1960

d-329

curvature

B

A

d-307

angle of deviation

d-285

the center of the circle to any point on the circumference (edge)

d-263

meniscus

A·I·R ©1960

(127)

d-248

concave

d-270

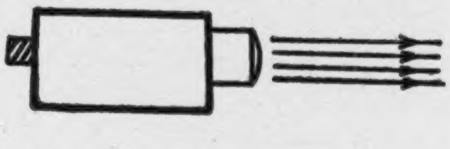
convex

converge (or, meet, come together)

d-292

center of curvature

d-314



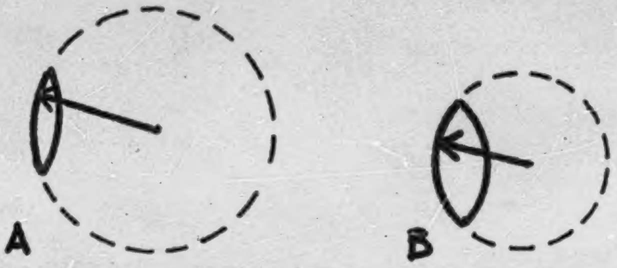
d-336

focal length

A·I·R ©1960

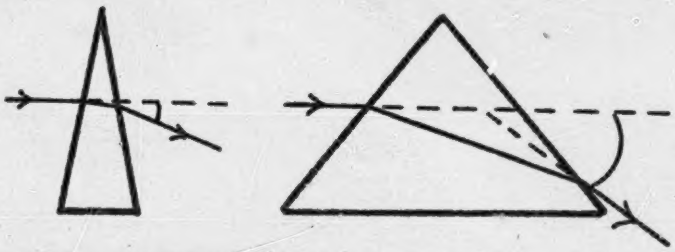
D-329

A sharply curved lens is one which has a small radius of ______. Lens $ is more sharply curved than lens $.



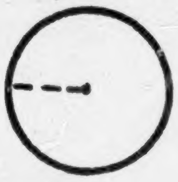
D-307

The angle of deviation for prisms, made of any one kind of refractive medium, depends on the angle made by the sides of the prism. As shown in the figure, as the angle of the prism's sides is increased, the * becomes greater.



D-285

A radius of a circle is the distance indicated by a line from ** ______.



D-263

Many people wear glasses. The lenses are usually crescent-shaped. We call this kind of a lens a ______ lens.

821

A·I·R ©1960

D-249

A convex surface is formed with a characteristic outward bulge, as in Figure 1. The lens in Figure 2 has two ☐ surfaces.

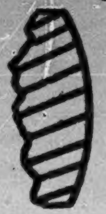


FIG. 1

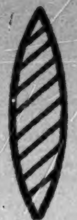
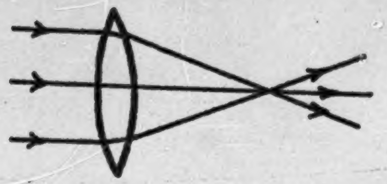


FIG. 2

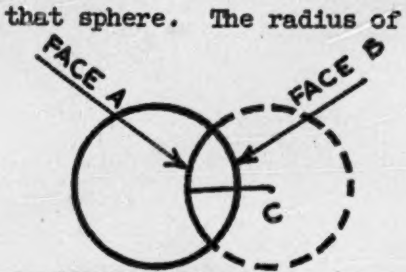
D-271

We want the parallel rays of light entering a telescope to converge to form a sharp image at the eyepiece. In order to make light converge, the lens must have a ☐ shape.



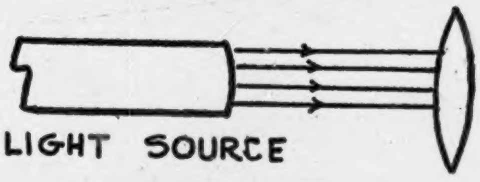
D-293

The center of curvature of lens face A is the center of the sphere formed by the dotted lines. The radius of curvature of the lens face is the radius of that sphere. The radius of curvature of the lens face and the ☐ of the sphere are both a line drawn from the ☐ * to any point on the ☐ of the lens face.



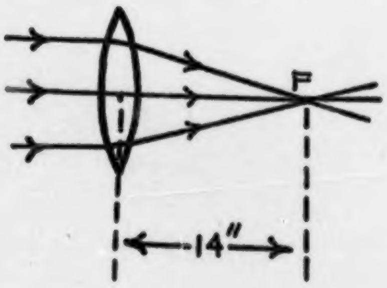
D-315

Parallel light beams reaching a lens are bent by a convex lens so that they converge on the other side of the lens. Draw in the converging rays in this figure.



D-337

Light beams converge 14 inches from the lens in this drawing. In this case, 14 inches is the focal length of the lens, the distance between the lens and the ☐ *.



A·I·R ©1960

END OF UNIT

d-328

curvature
foci

d-306

angle of deviation

d-284

radius

d-262

meniscus
concave (convex)
convex (concave)

A·I·R ©1960

d-249

convex

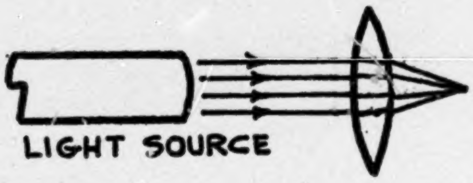
d-271

convex

d-293

radius
center of curvature (or, center of the sphere, point C)
surface

d-315



d-337

principal focus (or, focal point)

A·I·R ©1960

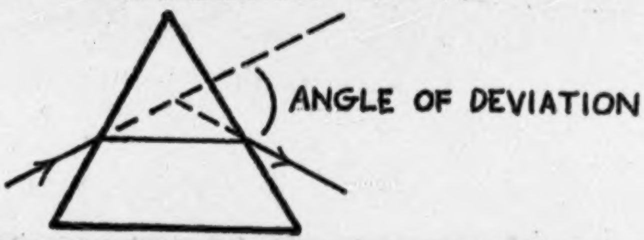
END OF UNIT

D-328

All convex lenses have two radii of curvature, two centers of ______, and two principal ______.

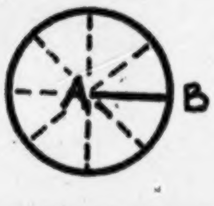
D-306

Light is bent as it passes through each surface of a prism. The angle formed by the incoming ray and the outgoing ray is called the angle of deviation. The amount which a ray of light passing through a prism changes direction is called the * ______ ______.



D-284

The phrase "radius of a circle" is a familiar one. In the drawing, the line AB, from the center to the circumference (or edge) of the circle, is a radius. However, any line from the center to any point on the circumference would also be a ______.



D-262

The two lenses shown are both known as ______ lenses. Notice that each one has one ______ and one ______ surface.

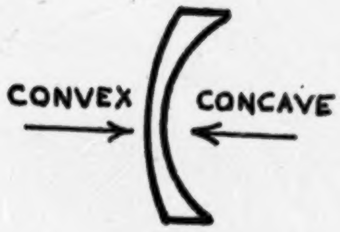


FIG. 1

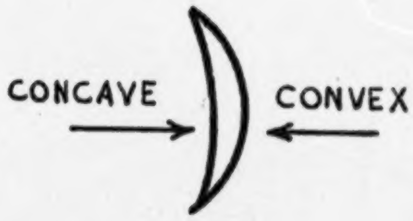


FIG. 2

A·I·R ©1960

D-250

If we join together two lenses which each have a concave surface, we will have a lens (Fig. 3) called a double ☐ lens.

FIG. 1

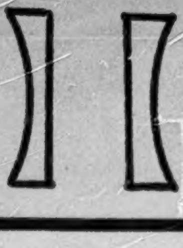


FIG. 2

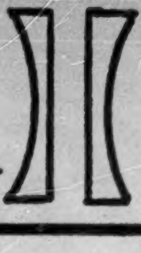
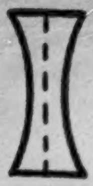
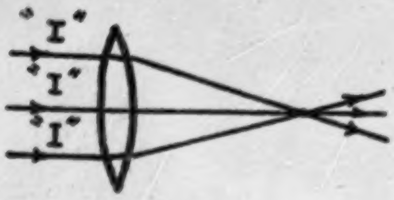


FIG. 3



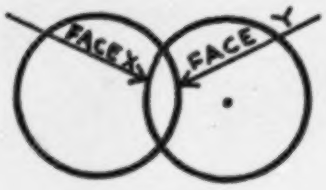
D-272

The diagram below indicates the path of light through a convex lens. "I" shows the incoming light rays. Label the converging beams with a "C," and the point where they meet with an "F."



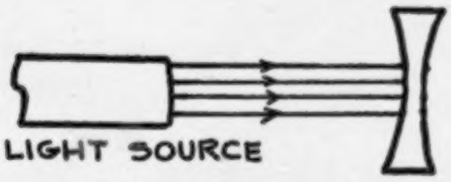
D-294

Draw in the radius of curvature for lens face X below and mark the center of curvature with a "C."



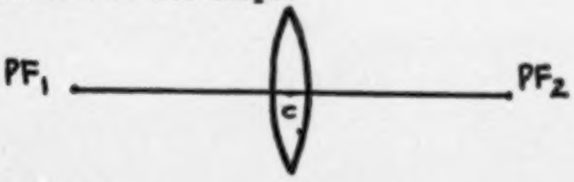
D-316

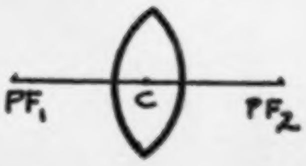
Parallel light beams are bent by a concave lens so that they diverge beyond the lens. Draw in the diverging rays to show the bending of light rays by this kind of lens.



D-338

Points PF_1 and PF_2 are the principal foci of the two lenses below. Their optical centers are labeled C. For each lens, the distance from C to either PF_1 or to PF_2 is always (the same/different) ☐. The ☐ lengths are the same on either side of a lens, regardless of its shape.





A·I·R ©1960

d-349

inverted
upside down

d-327

foci
side of the lens

d-305

30°
50°

d-283

sphere

d-261

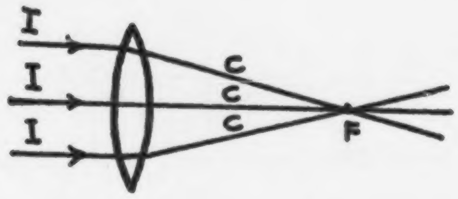
meniscus

A·I·R ©1960

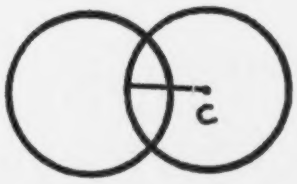
d-250

concave

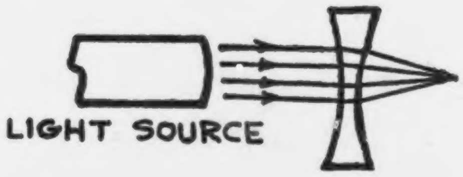
d-272



d-294



d-316


LIGHT SOURCE

d-338

the same
focal

A·I·R ©1960

D-349

A convex lens always produces a "real" image which is [   ]. The word means that the image is [*   ].

D-327

The plural form of focus is "foci," pronounced "fo-sy." Every lens has two principal [   ]. They are located on either [*   ].

D-305

The sides of a prism form an angle. This angle can be expressed in degrees. In the drawings, Figure 1 is a [#   ] degree prism and Figure 2 is a [#   ] degree prism.

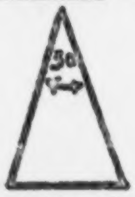


FIG. 1

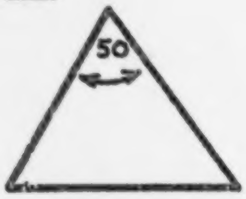
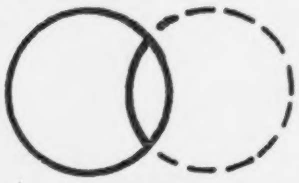


FIG. 2

D-283

If either face of a convex lens were extended; that is, if the curve of either face were continued on around, it would form a sphere. The lens' curved surface is, in other words, actually a part of the surface of a [   ].



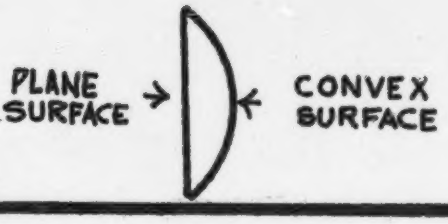
D-261

A meniscus (or crescent-shaped) lens has two faces which curve in the same direction. The figure shows a crescent-shaped or [   ] lens.

A·I·R ©1960

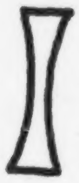
D-251

Both surfaces of a lens do not have to be curved. Many lens combinations have one curved surface and one straight or flat side, called a plane surface. For example, a convex surface could be combined with a ______ surface, as in the drawing.



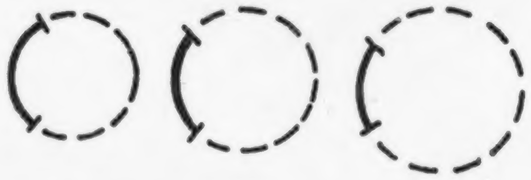
D-273

Surfaces which curve inward are known as concave surfaces. A lens having two concave surfaces would be known as a double ______ lens.



D-295

An equal sized piece of the surface of each sphere has been darkened. Notice that, as the radius of the sphere increases, the amount of sharpness, or the curvature of the piece, becomes (greater/less) ______.



D-317

A convex lens causes parallel light rays to bend toward each other, or converge. A concave lens also causes parallel light rays to bend. However, a concave lens makes the rays bend away from each other so that they fan out or ______.

D-339

Paper will burn if the sun's rays are focused on the paper with a lens. By moving a magnifying glass up and down between the sun and a sheet of paper, we can find a spot where the sun's converging rays would burn the paper. The distance between the burning paper and the lens is the * ______ of the magnifying glass.

A·I·R ©1960

d-348

conjugate
conjugate

d-326

principal focus

d-304

prism (or, glass)
parallel
will

d-282

double convex
converge (or, come together)

d-260

crescent (or, meniscus)

A·I·R ©1960

d-251

plane

d-273

concave

d-295

less

d-317

diverge

d-339

focal length

A·I·R ©1960

D-348

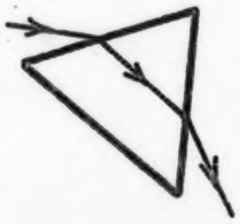
The word "conjugate" refers to any two related measurements in optics. The two focal points of a lens are known as ________ points and the distances to the object and image are known as ________ distances.

D-326

We could send parallel rays of light through a lens, and find its principal focus. If we turned the lens over, we would get the same result. There is a focal point or a * ________ on either side of a lens.

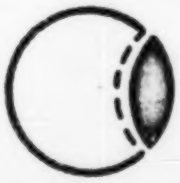
D-304

To understand how lenses work, it is helpful to see how light is refracted by a prism. We know that light is bent twice, once as it enters the prism from the air, and then again as it leaves the ________. Because the sides of a prism are not ________, a light ray passing through the prism (will/will not) ________ leave the prism in a different direction than it entered.



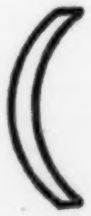
D-282

The darkened portion which was removed from the sphere in the drawing could, if it were made of glass, be used as a lens. Because of its shape, it would be called a * ________ lens. A lens such as this will cause parallel rays of light to ________.



D-260

Another type of lens is crescent-shaped; that is, the curvature of both surfaces is in the same direction. This type of lens, like the one in the figure, is called a meniscus lens (pronounced "men-is-kus"). It is identified by its ________ shape.



A·I·R ©1960

D-252

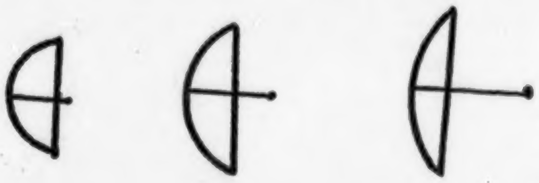
A surface may be plane, concave, or convex. A lens, which has two surfaces, may have one flat side called a ________ surface and another curved side which is either ________ or ________.

D-274

The opposite of converging (traveling toward a point) is "diverging," which means to fan out or move apart. Students meet at school in the morning; they travel different directions at night to return to their homes. We could say that their paths are ________ in the morning and ________ at night.

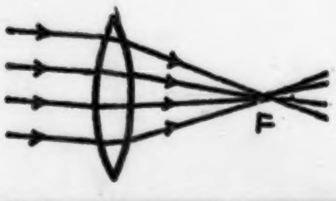
D-296

Large spheres have a long radius; small spheres have a * ________. As the radius of curvature is increased, the sharpness of curvature of the lens face (increases/decreases) ________.



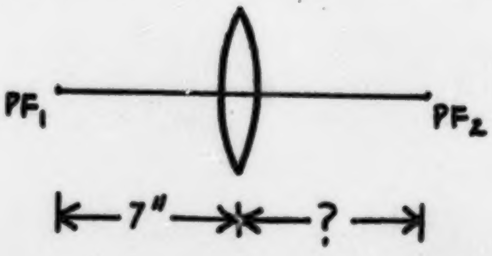
D-318

Converging lenses are ordinarily built so that they cause parallel rays of light to meet at a single point. We call this common meeting point of incoming parallel rays a focal point. In the diagram, point F is the * ________ for this convex lens.



D-340

The focal length on either side of a lens is always the same, regardless of the shape of the lens. In the figure, the focal length of PF_1 is seven inches. The distance to PF_2 or the second * ________ is also # ________ inches.



A·I·R ©1960

d-347

conjugate

d-325

principal focus (or, focal point)

d-303

meniscus

less

d-281

convex

d-259

A. plano-convex

B. double concave

C. double convex

A·I·R ©1960

⑭③

d-252

plane
concave (convex)
convex (concave)

d-274

converging
diverging

d-296

short radius
decreases

d-318

focal point

d-340

focal length
7

A·I·R ©1960

D-347

The dictionary defines the word "conjugate" (pronounced con-jew-gate) as "joined together," hence, a pair. This term in optics is used to refer to pairs of related measurements. The object distance and the image distance are a pair of related measurements which may be referred to as ☐ distances.

D-325

Ordinarily, we show parallel light beams traveling from left to right through a lens, converging at the principal focus as in Fig. 1. But parallel light could originate on the right and converge at a principal focus on the left as in Fig. 2. This would demonstrate that every lens has two locations for the ☐ *.

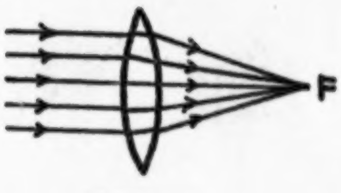


FIG. 1

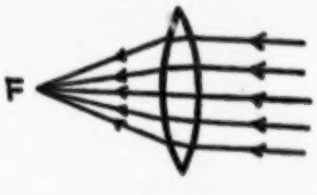
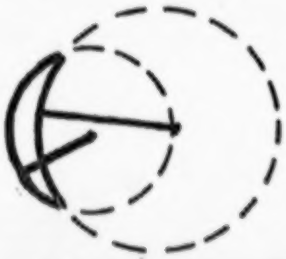


FIG. 2

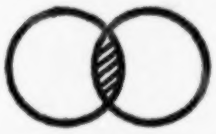
D-303

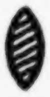
The surfaces of a ☐ lens, as the one in the figure, are also portions of imaginary spheres. For any lens face, the longer the radius of curvature, the (more/less) ☐ sharply the surface is curved.



D-281

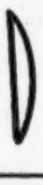
We might describe a lens as a solid piece of glass whose surfaces represent part of a sphere. In the drawing, we show the intersection of two spheres. The shaded portion where they meet forms the two faces of the type of lens known as a ☐ lens.



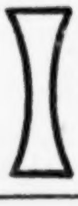


D-259

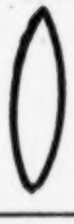
The three drawings below represent a double concave lens, a double convex lens and a plano-convex lens. Label A, B, C correctly.



A. ☐



B. ☐



C. ☐

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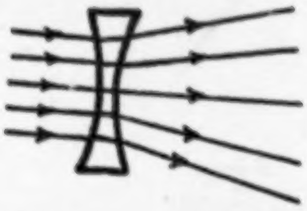
D-253

The lens drawn below is called a plano-convex lens because it has one plane (or, straight) side and one convex surface. "Plano" comes from the word "plane" which we know refers to a ________ surface.

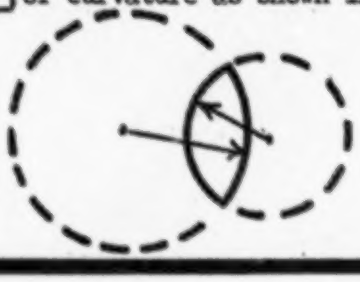
D-275

We have dealt with the convex lens which caused parallel light rays to converge. A concave lens causes parallel light rays to spread out in a fan-shape, or diverge. For this reason, a concave lens may also be called a ________ lens.



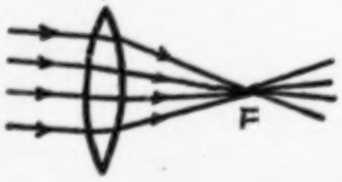
D-297

The plural form of radius is radii. Each lens face has its own radius of curvature; the two separate surfaces of a lens have two separate ________ of curvature as shown in the figure. One lens face may be more sharply curved than the other.



D-319

The focal point of a convex lens is the point at which incoming parallel rays ________. Point F is the * ________ in this drawing.



D-341

So far, we have only talked about the effect a lens has on incoming rays of light which are parallel. Parallel rays of light will form a clear, sharp image or be ________ at the * ________.

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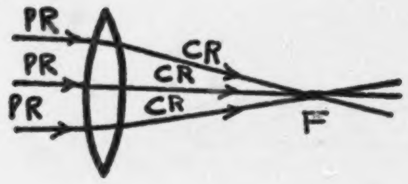
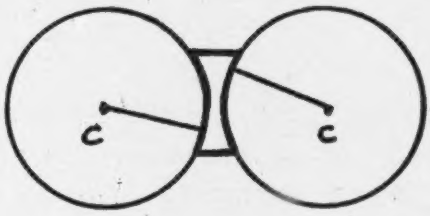
d-346

inverted

d-324


PR
PR
PR
CR
CR
CR
F

d-302



d-280

(lens) A

d-258

plano-concave

A·I·R © 1960

d-253

flat (or, straight or plane)

d-275

diverging

d-297

radii

d-319

meet
focal point

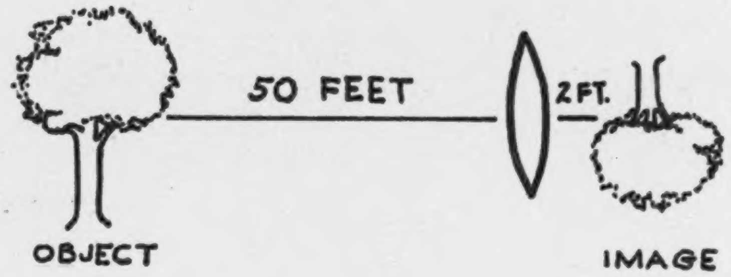
d-341

focused
principal focus (or, focus point)

A·I·R ©1960

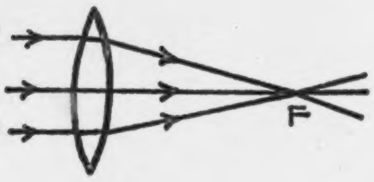
D-346

As you noticed in the figure, the image is inverted. A "real" image (the kind that can be projected on a screen) produced by a convex lens will always be upside down or ______.



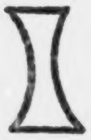
D-324

In the figure, label each parallel ray "PR," each converging ray "CR," and the principal focus "F."



D-302

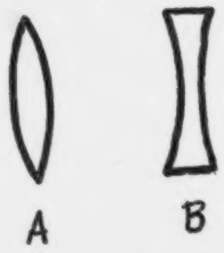
Extend the curvature of the faces of this concave lens to show the imaginary spheres they are part of. Draw in two centers of curvature and label them "C". Draw in two radii of curvature.



D-280

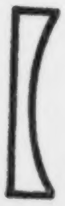
A typical use for a converging lens is in a telescope. This lens collects the incoming light rays so they converge or meet at our eye.

We would choose lens (A/B) $ ______ for this purpose.



D-258

This is a lens which has one straight side. The other surface is curved so that the lens is thinner at the center than it is at the edges. This combination is called a ______ lens.



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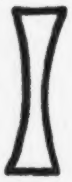
D-254

A plano-convex lens combines two different types of surfaces. One is a [ ] surface, and the other is a [ ] surface. Draw a plano-convex lens.

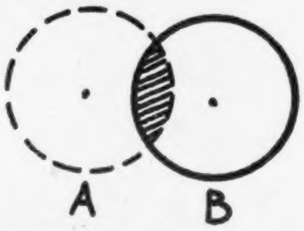
D-276

A diverging lens is drawn below. It is different from a converging lens because its surfaces are [ ] rather than convex. In use, it is different from a convex lens because it makes light beams [ ] instead of [ ].



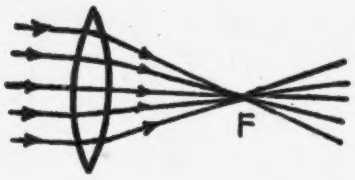
D-298

Two intersecting spheres are shown below, marked A and B. Draw in the radius of curvature for the lens surface shown by the heavy line. Since the lens surface is part of the surface of sphere B, the radius drawn is also the radius of sphere [$].



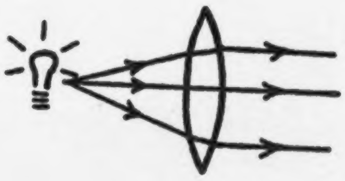
D-320

We can shape a lens so that all parallel rays meet at one particular point. We say that we have focused these rays. In the drawing, the converging rays have been [ ] at point F. This point is known as the [*].



D-342

When we look at an object through a lens, the incoming rays of light are not all parallel. Suppose we place a small light source at the focal point of a lens. Although the incoming rays are not parallel, we know, because of principle of the reversibility of light, that the refracted rays will be [ ].



A·I·R ©1960

d-345

50 (feet)
2 (feet)

d-323

principal focus

d-301

concave lens

d-279

diverge

d-257

double convex
double concave

A·I·R ©1960

151

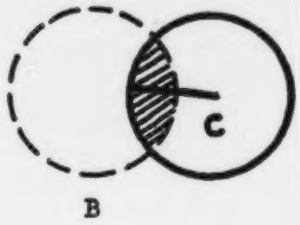
d-254

plane (or, flat)
convex (or, curved)

d-276

concave
diverge
converge

d-298



d-320

focused
focal point

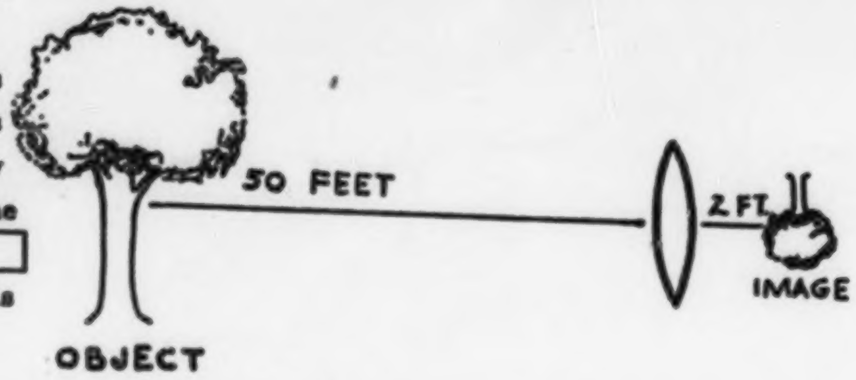
d-342

parallel

A·I·R ©1960

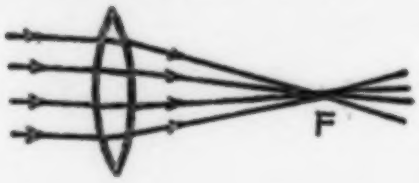
D-345

The image distance is the distance between the lens and the clear image formed by the lens. In the drawing, the object distance is # feet and the image distance is # feet.



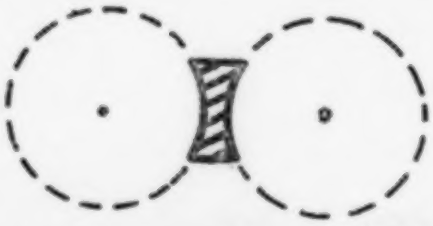
D-323

A converging lens causes parallel incoming rays to meet at a point. This point is called a focal point of the principal focus. This lens shows converging rays of light. Point F is the * or focal point of this lens.



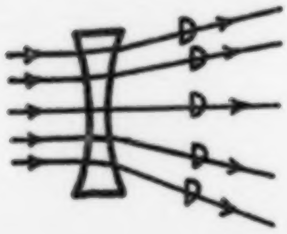
D-301

So far, we have discussed the center of curvature and radius of curvature of convex lenses. This figure shows that the faces of a * are also portions of imaginary spheres.



D-279

Light is dispersed, or spread out, after refraction through a concave lens. In the diagram below, the rays marked "D" are examples of light rays which ☐ or spread out.



D-257

A concave and a convex surface are opposite in curvature. It is easy to remember the difference by remembering that a convex lens is larger in the middle and thinner at the ends, while a concave lens is thin at the center and thick at the edges. Fig. 1 is a * lens; Fig. 2 is a * lens.

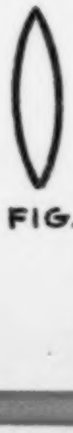


FIG. 1

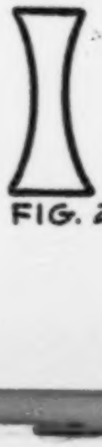
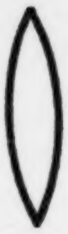


FIG. 2

A·I·R ©1960

D-255

The lens pictured is not a plano-convex lens, because both sides are ☐. The shape tells us that it is a double ☐ lens.

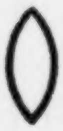


D-277

Concave lenses make parallel rays of light ☐. Convex lenses cause parallel rays of light to ☐.

D-299

Each lens surface is part of the surface of a separate sphere. Extend both faces of the lens below to show the two separate intersecting spheres involved. Mark the center of curvature of each lens with a "C" and draw in the two radii of curvature.



D-321

A woman adjusting her hat in front of a mirror is looking at her own image. The same term is used with lenses. The view of an object seen through a lens is also called an ☐.

D-343

To project parallel rays, we can place a small source of light at the ☐ * of a convex lens.

A·I·R ©1960

d-344

object distance

d-322

image

d-300

centers of curvature (radii of curvature)
radii of curvature (centers of curvature)

d-278

convex
concave

d-256

plano-convex

A·I·R ©1960

155

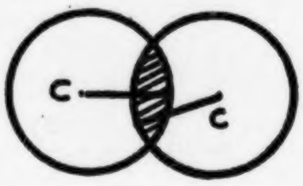
d-255

curved (or, convex)
convex

d-277

diverge
converge

d-299



d-321

image

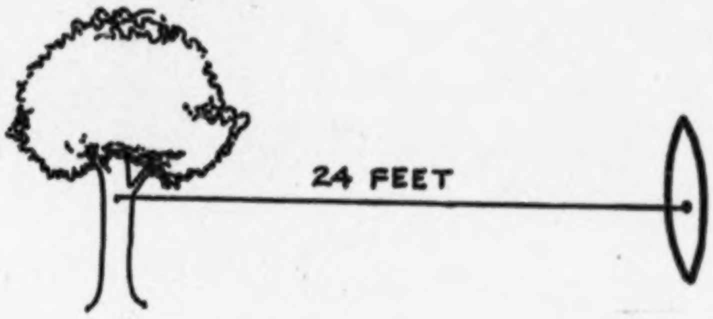
d-343

principal focus (or, focal point)

A·I·R ©1960

D-344

When we refer to the distance between a lens and an object, we speak of the object distance. In the diagram, 24 feet is the [*], measured from a tree to a lens.



D-322

The visual impression of an object which our eyes receive is called an image. A lens focuses light to form an [ ] of the original object.

D-300

Each lens surface has its own individual center of curvature and its own radius of curvature. Since we know that every lens has two surfaces, we know that each lens must have two [*] and two [*].

D-278

Converging light beams are caused by the bending of light by a [ ] shaped lens, and diverging light rays result from the use of a [ ] shaped lens.

D-256

A solid glass ball could be cut in half. These halves might be used as lenses, each having one plane and one convex face. Technically, this combination shown in Fig. 2 would be called a [ ] lens.

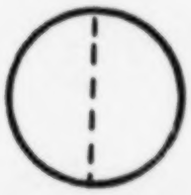


FIG. 1

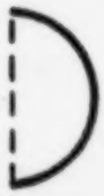


FIG. 2

A·I·R ©1960

X ⑮⑦

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

159

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UNIT 4

IMAGE FORMATION

Steps D-350 through D-494

X⑧

BEGIN UNIT HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

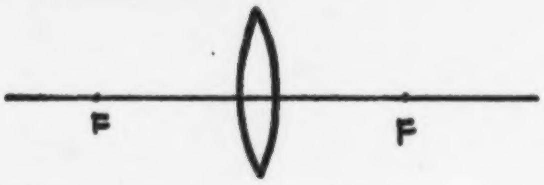
TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

UNIT ENDS HERE

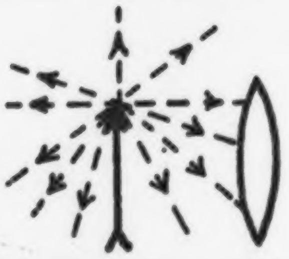
D-350

The principal foci, F_1 and F_2 in the drawing are connected by a line drawn perpendicular to both lens faces. This is the principal axis of the lens. A line which passes through the optical center of the lens and both of the principal foci is known as the * ______ ______ of the lens.



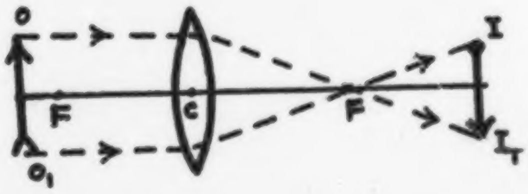
D-380

The figure shows a source of light shaped like an arrow. Several rays of light are shown coming from the tip of the arrow. Only those which strike the lens will be ______ by the lens.



D-410

In the drawing, an object (an arrow) is shown. Its image is formed on the other side of the lens. Light from the object has travelled through the convex lens, and formed an ______. Notice that the image is farther from the lens than F, the * ______.



D-440

The image produced by a concave lens is always a ______ image. The image will always be (larger/smaller) ______ than the object. All virtual images are (upright/inverted) ______.

D-470

The image distance is the distance between the ______ and the * ______ ______ of the ______.

A·I·R ©1960

d-469

object
lens

d-439

virtual
smaller

d-409

image
all

d-379

image

A·I·R ©1960

d-350

principal axis

d-380

refracted (or, converged, focused)

d-410

image
focal point (or, principal focus)

d-440

virtual
smaller
upright

d-470

image
optical center
lens

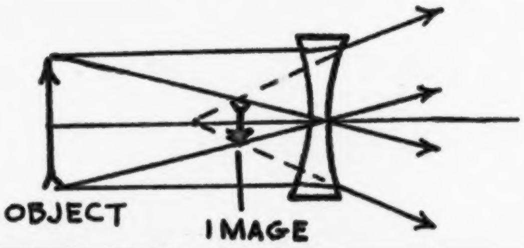
A·I·R ©1960

D-469

In optics, we define the object distance as the distance between the ______ and the optical center of the ______.

D-439

The image produced by a concave lens is upright. It appears to be on the same side of the lens as the object. A ______ image is produced by a concave or diverging lens. The image produced by a concave lens is always (larger/smaller) ______ than the object.



D-409

Many rays travel from each point on the object. They pass through the lens and converge at one point on the image. All rays from any one object point meet at only one ______ point. The image point is where (some/all) ______ rays from the corresponding object point meet.

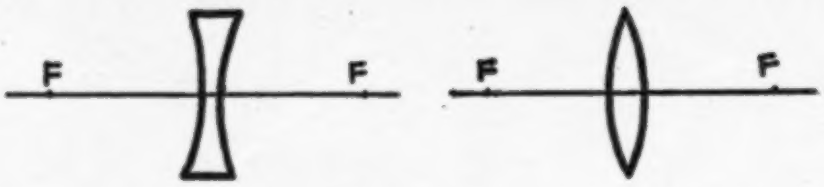
D-379

Any object we can see can be regarded as a source of light, whether it emits light or reflects light which is shining on it. If we view the light coming from an object through a lens, we will see an ______ of the object.

A·I·R ©1960

D351

The principal axis may be drawn for any kind of lens. A straight line, passing through the center of the lens and perpendicular to both faces, will pass through both ______ points. Such a line is known as the * ______ of the lens.

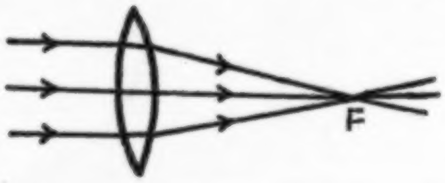


D-381

Light which does not strike a lens does not help form an image. In describing the way in which an image is formed through a lens, we are only concerned with the rays of light which pass through the ______.

D-411

The location of an image point is located where light rays coming from the corresponding object point intersect. If only parallel rays enter the lens, the rays will meet at the * ______ as in the figure.

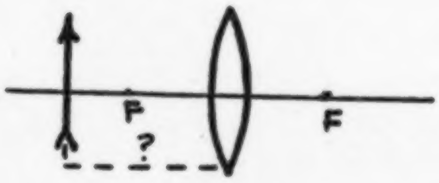


D-441

Even though we show where an image point is located using only two lines, we know that all the rays of light from any one ______ point which strike the lens converge or ______ at the corresponding image point.

D-471

In studying image formation, we use diagrams like this. It shows where the object was with respect to the focal point, but we did not indicate the actual object ______ in inches.



A·I·R ©1960

d-468

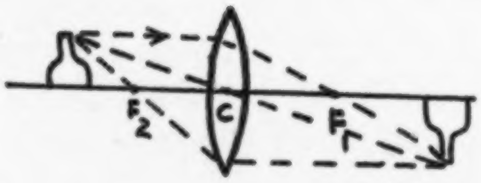
focal point

d-438

same

closer to

d-408



d-378

image

(991)

A·I·R ©1960

167

d-351

focal
principal axis

d-381

lens

d-411

focal point

d-441

object
meet (or, focus)

d-471

distance

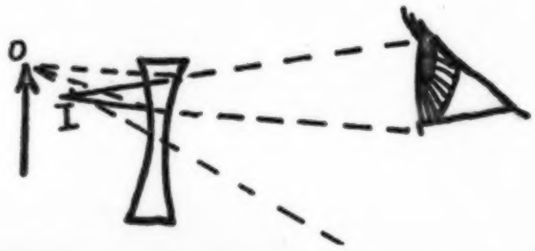
A·I·R ©1960

D-468

The focal length of a lens is the distance between the lens and the principal focus or * ______.

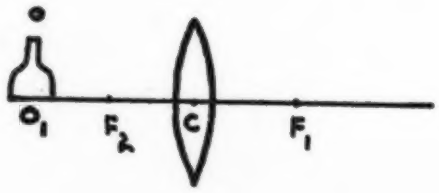
D-438

An image seen through a concave lens appears to be on the (same/opposite) ______ side of the lens as the object. It appears to be (closer to/farther from) ______ the lens than the object.



D-408

Draw in lines to show the formation of the image of this bottle (object).



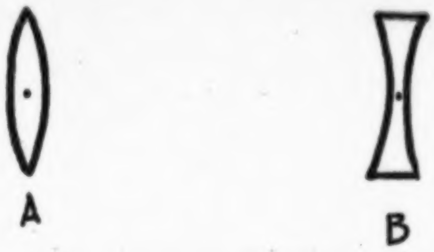
D-378

An image is the sharp, clear reproduction of an object which is formed on a screen, or seen directly by the eye, after the light from the object has passed through a lens. When we look at an object through a lens, we are seeing an ______ of that object.

A·I·R ©1960

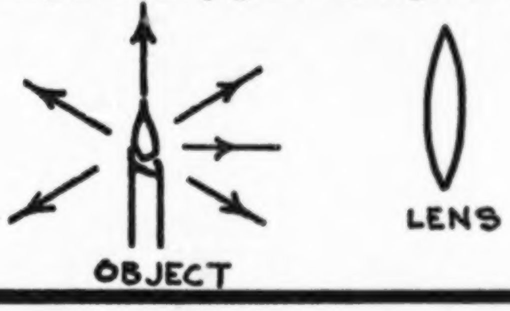
D-352

The shape of A tells us that this is a double ☐ lens and that B is a double ☐ lens. Draw in the principal axis for each type of lens.



D-382

Light travels in straight lines. Although an object usually gives off light in all directions, only the light which ☐ * helps form the image.

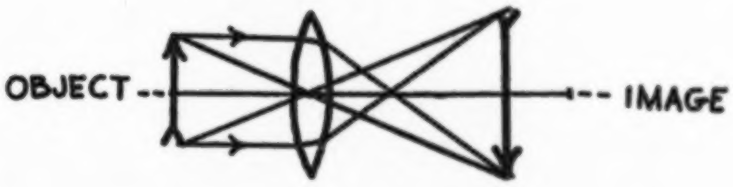


D-412

If only light rays parallel to the principal axis enter a convex lens, they will meet at the focal point. Light rays coming from an object (are/are not) ☐ all parallel to the principal axis. Therefore, the image formed by a convex lens (will/will not) ☐ always be formed at the focal point.

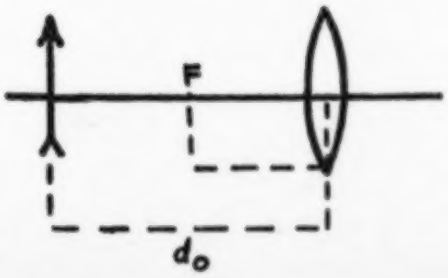
D-442

Light traveling from an object through a converging lens will form an ☐ of that object on the other side of the lens. It will be a ☐ image. The size of the image depends on the object distance; that is, how far the object is from the ☐.



D-472

We abbreviate object distance as "d_o" (say, dee-sub-oh) and focal length as "f." In this drawing, d_o is (greater than/less than) ☐ F.



A·I·R ©1960

d-467

virtual

d-437

concave

I

d-407

inverted

d-377

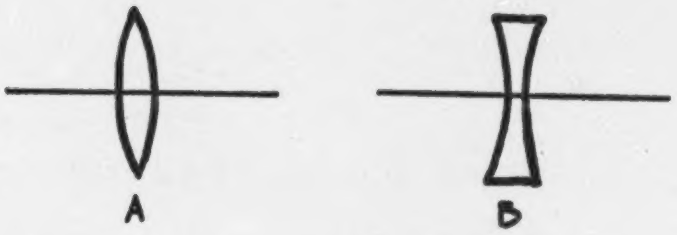
opaque

(120)

A·I·R ©1960

d-352

convex
concave



d-382

passes through (or, travels through, strikes) a lens

d-412

are not
will not

d-442

image
real
lens

d-472

greater than

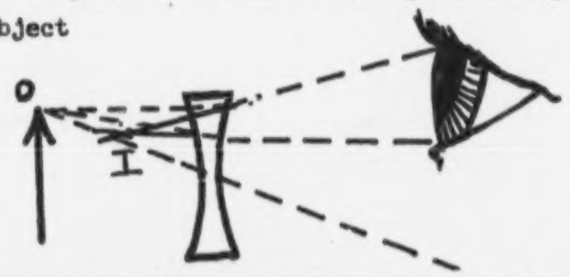
A·I·R ©1960

D-467

All diverging lenses, and also converging lenses when the object distance is less than one focal length, produce ________ images. We will consider these images in detail in dealing with magnification.

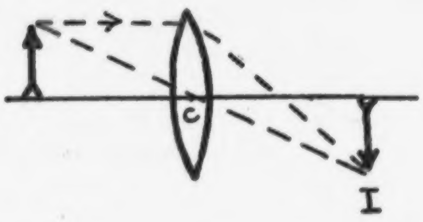
D-437

This figure shows how an object appears to our eye when we see it through a diverging or ________ lens. The light representing any one object point, O, seems to be coming from a single image point, [$] very near to the lens.



D-407

In the diagrams of image formation you have seen so far, the image point for any object point has been on the other side of the principal axis. In all these instances the image would be upside down, or, ________.



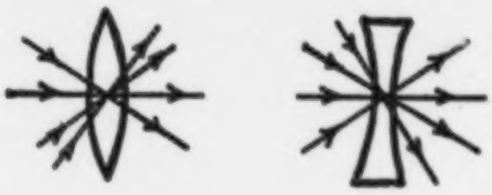
D-377

To measure the size of a spot of light, the light rays must fall on an ________ surface after passing through a lens.

A·I·R ©1960

D-353

Light which passes through a lens without bending has passed through the optical center of the lens. In this drawing, none of the rays have changed direction. These rays have all passed through the ______ center of the lens.



D-383

All the rays of light coming from any one point on the object which pass through the lens help form the corresponding point of the ______.

D-413

The image point corresponding to any object point will be located where ** ______.

D-443

If an object is very far from the lens, so far that the light entering the lens is parallel to the principal axis, the image that will be formed will be at F, the * ______. If the object is closer, the image will be formed farther from the lens.

D-473

If we know the lengths of d_o and f, we can calculate the exact length of the image distance. To calculate "d_i" (say, dee-sub-eye); that is, the image ______, we must know the lengths of $ ______ and $ ______.

A·I·R ©1960

d-466

virtual

d-436

virtual

d-406

axis
optical center

d-376

larger

A·I·R ©1960

175

d-353

optical

d-383

image

d-413

all the light rays coming from the object point (which pass through the lens) meet or intersect

d-443

focal point

d-473

distance

d_o

f

A·I·R ©1960

D-466

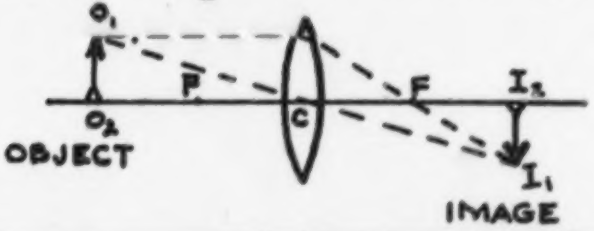
An object between 1 and 2F, or beyond 2F, will form a real image. An object between the lens and 1F forms an image which cannot be projected on a screen. It will be a ☐ image.

D-436

When our eye sees rays of light which are diverging after they have passed through a concave lens, the rays of light representing a given object point seem to come from an image point which is on the same side of the lens as the object. The image point we see is part of a ☐ image.

D-406

The figure shows the image formation for a small object which does not extend below the principal axis. Note that the image point corresponding to point O_2 must be somewhere along the principal ☐. A light ray which coincides with the principal axis will not be bent because it passes through the ☐* of the lens.



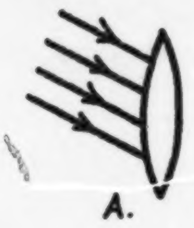
D-376

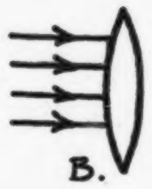
For a diverging lens, the farther away the screen is from a lens, the ☐ the spot of light becomes.

A·I·R ©1960

D-354

When we speak of parallel rays of light, with respect to a lens, we mean rays of light which are parallel to the principal axis. Both these figures show rays of light parallel to each other, but only figure B shows rays which are parallel to the [*].



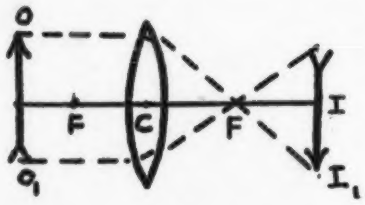


D-384

Any one image point is formed by [ ] the light which comes through the lens from a given [*].

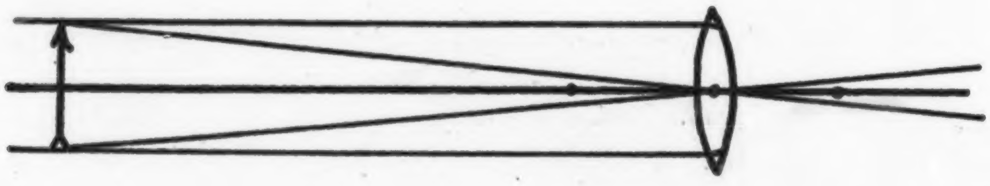
D-414

We define focal length as the distance between the lens and either [ ] point. The image distance is the measurement along the principal axis from the lens to the image. In the drawing, CF is the [*] and CI is the [ ] distance.



D-444

Draw the image of the arrow that will be formed by this lens.



D-474

If we know the object distance and the focal length of a lens, we can calculate the distance between the lens and the [ ].

A·I·R ©1960

END OF UNIT

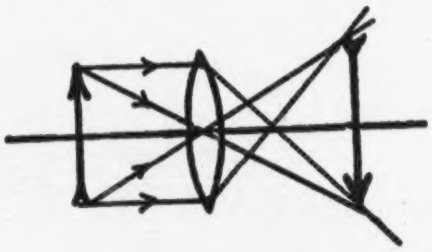
d-465

larger
smaller

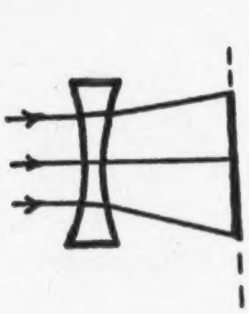
d-435

diverge
virtual

d-405



d-375



A·I·R ©1960

d-354

principal axis

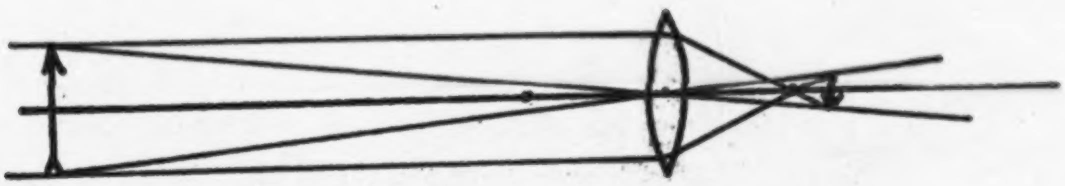
d-384

all
object point

d-414

focal
focal length
image

d-444



d-474

image

A·I·R ©1960

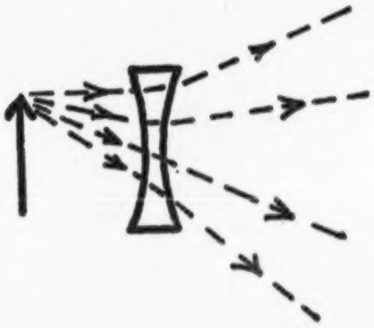
END OF UNIT

D-465

When an object is between 1F and 2F, the size of the image will be ☐ than the object. If the object is more than 2F from the lens, the image will be ☐ than the object.

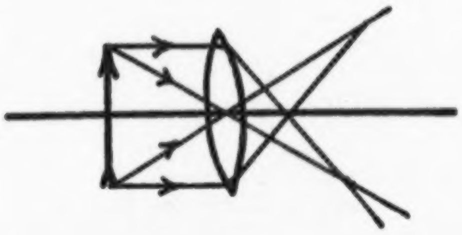
D-435

The rays of light coming from any one object point fan out, or ☐, as they pass through a concave lens. Therefore, an image seen through a concave lens is always a ☐ image.



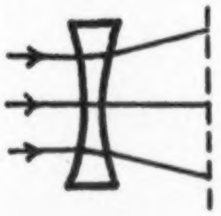
D-405

Draw the image corresponding to the object for this diagram.



D-375

The size of a spot formed when parallel rays of light enter a diverging lens is found in the same way. Using a heavy line, show the size of the spot in the figure below.



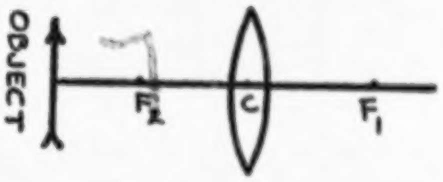
A·I·R ©1960

D-355

When we say that rays of light entering a lens are parallel, we mean both that the rays are ☐ to each other and that they are all parallel to the * of the lens.

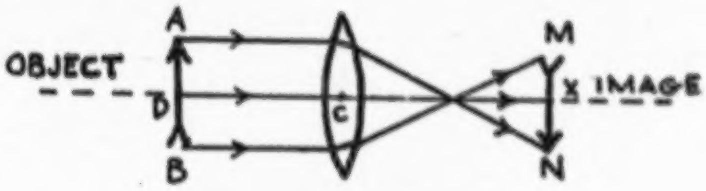
D-385

By applying rules you already know, you can draw a diagram to show how an image is formed. One line which helps locate where the image should be drawn is the principal axis, which passes through point C, the * of the lens. F_1 and F_2 on the principal axis, we know, are the two * .



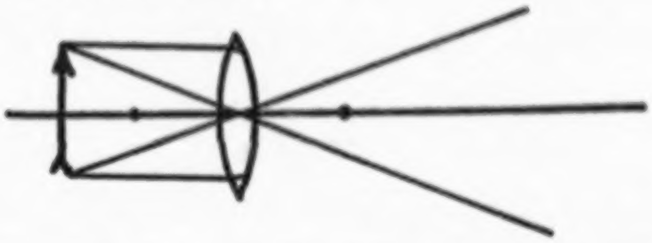
D-415

We define the image distance as the distance (in feet, inches, etc.) between the image and optical center, measured along the principal axis. The object distance is measured from D to C, and the image distance is measured from $ to $.



D-445

Draw the image of the arrow that will be formed by this lens.



D-475

To find the image distance, or $ we need to know the reciprocals of d_o and f. The reciprocal of a number is the fraction made by putting a "1" over that number. The reciprocal of d_o is $\frac{1}{d_o}$; the reciprocal of f is $.

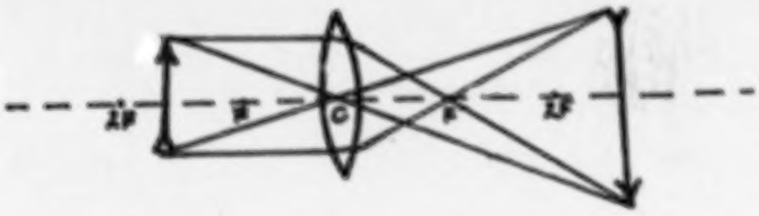
A·I·R ©1960

d-494

$(\frac{1}{d_i} = \frac{2}{12},\ d_i = \frac{12}{2},\ d_i =)$ 6 inches

---

d-464



larger

---

d-434

image

---

d-404

B
N
T

---

d-374

smaller
larger

A·I·R ©1960

d-355

parallel
principal axis

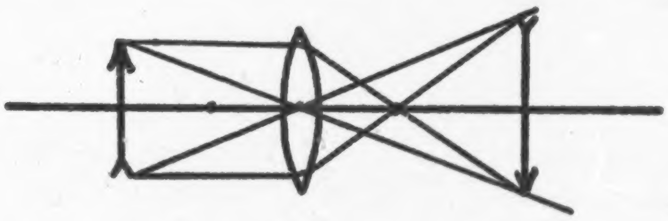
D-385

optical center
focal points (or, principal foci)

d-415

C (to) X

d-445



d-475

d_i

$\frac{1}{f}$

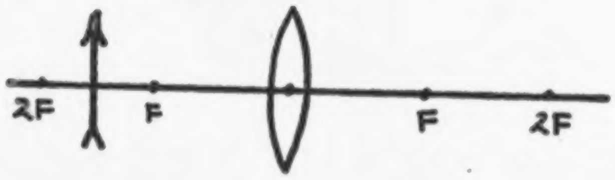
A·I·R ©1960

D-494

If the object distance of a lens is 12 inches, and the focal length is 4 inches, the image distance is * .

D-464

This object is between 1F and 2F. Locate and draw the image that would be formed. The image is (larger/smaller) ☐ than the object.

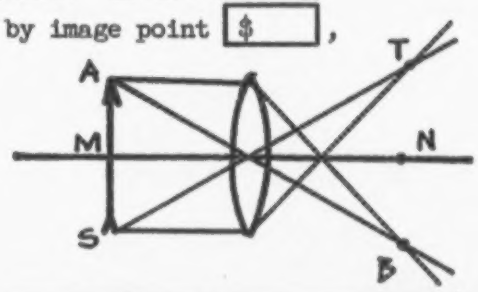


D-434

The image we see through a concave or diverging lens, is always a virtual image. The rays of light which pass through the lens from any one object point never meet to form a real ☐ point.

D-404

An image point can be located to correspond to every object point. In the drawing, object point A is represented by image point $, object point M by image point $, and object point S by image point $.



D-374

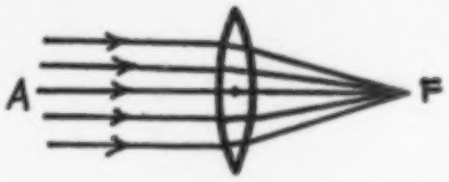
If the screen is very near the lens, the spot of light formed by converging parallel rays is large. Then, if we move the screen toward the focal point, the spot will get ☐ . If we move the screen past the focal point, the spot will then get ☐ again.

A·I·R ©1960

D-356

This figure shows what happens when parallel rays of light pass through a lens. Only one ray, AF, has not changed direction.

This ray, AF, has passed through the [*] of the lens.



D-386

The principal axis can be thought of as representing a ray of light coming from one point on the object. Since this ray of light passes through the lens, we know it must help form the corresponding [*]; that is, one image point must be somewhere on that line.

D-416

The distance between the optical center of a lens and the principal focus is the [ ] length. The distance from the optical center to the image is the [ ] distance. The distance from the optical center to the object is the [ ] distance.

D-446

If the object distance is very great, the image of that object produced by a convex lens will be (large/small) [ ]. As the object is moved nearer the lens, the size of the image will (increase/decrease) [ ].

D-476

We add or subtract the reciprocals of numbers just like we add or subtract fractions, by using the lowest common denominator. The lowest common denominator for $\frac{1}{3}$ and $\frac{1}{6}$ is 6. For $\frac{1}{2}$ and $\frac{1}{5}$ it is 10, and for $\frac{1}{4}$ and $\frac{1}{2}$ it is [#].

A·I·R ©1960

d-493

$\left(\frac{1}{f} = \frac{2}{4},\ f = \frac{4}{2},\ f =\right)\ 2$

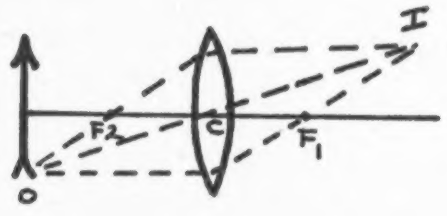
d-463

1 (and) 2

d-433

upright
cannot
same

d-403



(any two lines from object point O could have been used)

d-373

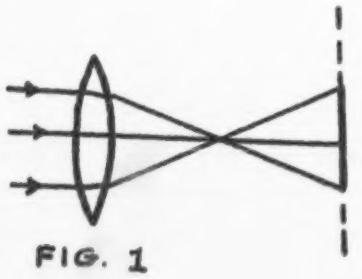


FIG. 1

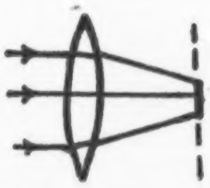


FIG. 2

A·I·R ©1960

d-356

optical center

d-386

image point

d-416

focal
image
object

d-446

small
increase

d-476

4

A·I·R ©1960

D-493

If d_i is 4 inches and d_o is 4 inches, the focal length of the lens is [#] inches.

D-463

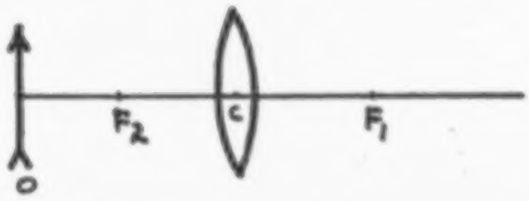
When we look at a building through a telescope, the object is at a great distance from the lens, beyond 2F. The image will be formed between [#] and [#] focal lengths.

D-433

A virtual image is (upright/inverted) [ ]. It (can/cannot) [ ] be focused on a screen. It is on the (same/opposite) [ ] side of the lens as the object.

D-403

Every point of the image can be located with lines representing two rays of light. Show how the bottom of the arrow (object) will form an image point beyond the lens. Label the image point "I."



D-373

Draw in a heavy line in each of the figures below to show the size of the spot of light that would appear on the screen.

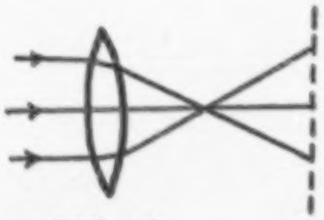


FIG. 1

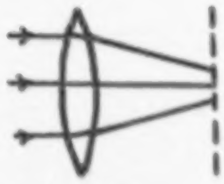


FIG. 2

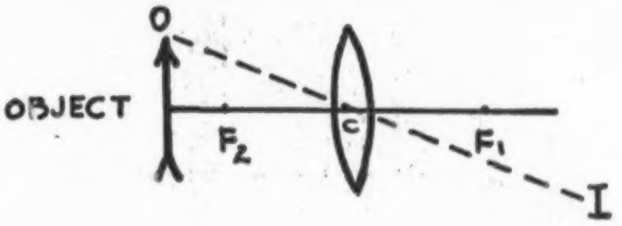
A·I·R ©1960

D-357

All lenses have one particular point through which a beam of light may pass without changing direction. Light is not bent when it passes through the * ____ of a lens.

D-387

We have defined a secondary axis as a straight line passing through the * ____ of a lens. A secondary axis is shown in the drawing, passing from the tip of the object (point O) through the * ____ of the lens. Line OCI is an example of a * ____.

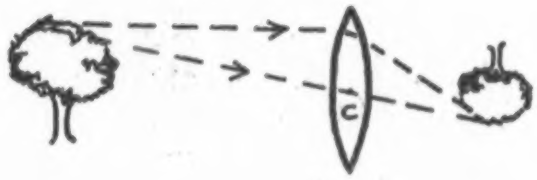


D-417

A clear or distinct image is formed when all the light from one point on the object is focused perfectly at a corresponding point on the image; that is, when all the light from one object point is focused exactly at one ____ point.

D-447

If an object is far from the lens, most of the rays striking the lens will be almost parallel to each other. These rays will converge to form a very small ____ because the object distance is very (large/small) ____.



D-477

To add $\frac{1}{2} + \frac{1}{3}$, we first have to change the problem so that both parts have the same denominator. Since the lowest common denominator is # ____, we write the problem as $\frac{3}{6} + \frac{2}{6}$.

To add $\frac{1}{2} + \frac{1}{6}$ we would write the problem as # ____.

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d-492

$\frac{1}{d_o} = \frac{1}{d_i}$

$(\frac{1}{2} = \frac{1}{5} + \frac{1}{d_o}, \frac{1}{d_o} = \frac{1}{2} - \frac{1}{5}, \frac{1}{d_o} = \frac{3}{10}, d_o = \frac{10}{3}, d_o =)$ 3.33

---

d-462

B
smaller

---

d-432

inverted
can
opposite

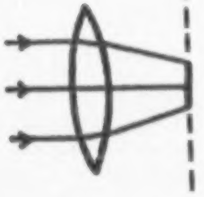
---

d-402

I

---

d-372



A·I·R ©1960

d-357

optical center

d-387

optical center
optical center
secondary axis

d-417

image

d-447

image
large

d-477

6
$\frac{3}{6} + \frac{1}{6}$

A·I·R ©1960

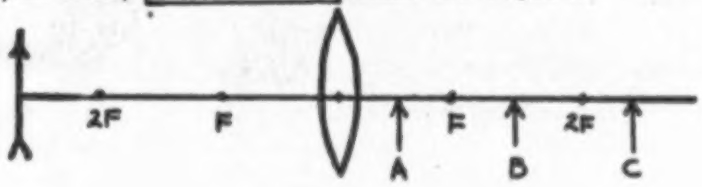
D-492

We can also find d_o, knowing d_i and f, by using the formula $\frac{1}{f} = \boxed{\$\qquad}$.

If $d_i = 5$ and $f = 2$, $d_o = \boxed{\#\qquad}$.

D-462

The object below is beyond 2F. If you draw the image, you will see that the image will form at point $\boxed{\$\quad}$. The image is (larger/smaller) $\boxed{\qquad\quad}$ than the object.

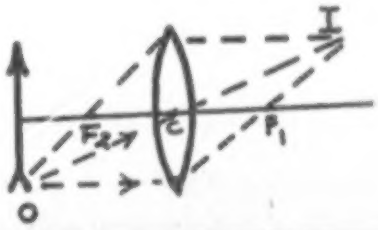


D-432

A real image is (upright/inverted) $\boxed{\qquad\quad}$. It (can/cannot) $\boxed{\qquad}$ be focused on a screen. It is on the (same/opposite) $\boxed{\qquad\quad}$ side of the lens from the object.

D-402

In the drawing, lines from point O on the object form an image point beyond the lens at point I. In other words, the image of point O of the arrow, is formed at point $\boxed{\$\quad}$, where the rays meet.



D-372

The size of a spot of light formed by converging parallel rays of light is found by seeing where the outermost rays strike the screen. In Figure 1, the dark line has been drawn at the screen to indicate the size of the spot. Do the same for Figure 2.

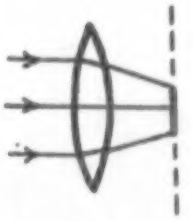


FIG. 1

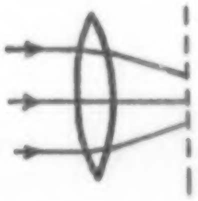
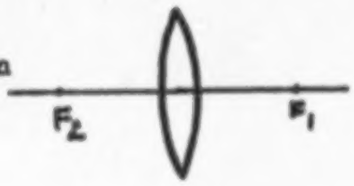


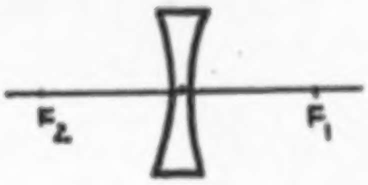
FIG. 2

A·I·R ©1960

D-358

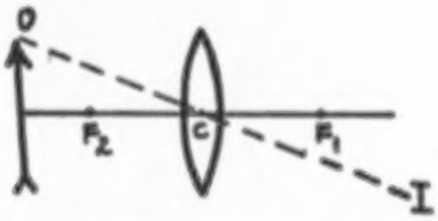
The principal axis of a lens is perpendicular to the faces of a lens. It passes through the [*] of the lens as well as the two focal points. The lines drawn through these lenses are each an example of a [*].





D-388

OCI is a secondary axis of the lens. Since light travels foom point O on the object through the lens, we know that the image of point O will be formed somewhere along line [$]. All the light which leaves a given object point and passes through the lens meets at one [ ] point.



D-418

There is only one image distance where the image will be sharp and clear. If we place an opaque screen at any other distance, the image we see will be out of [ ].

D-448

If an object is placed nearer to the lens, the image can be much larger than the object. When we use a movie projector, for instance, the object (or film) is placed near the lens and the image produced is then [*] the object.

D478

Try this problem, $\frac{1}{5} + \frac{1}{4} =$ [#].

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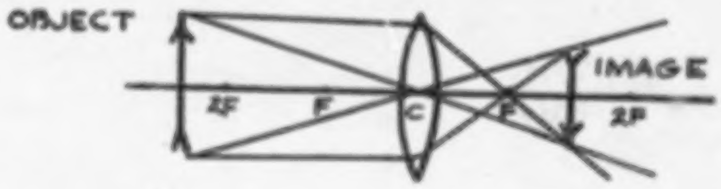
d-491

object distance
image distance

---

d-461


OBJECT
IMAGE
2F
F
C
F
2F

smaller

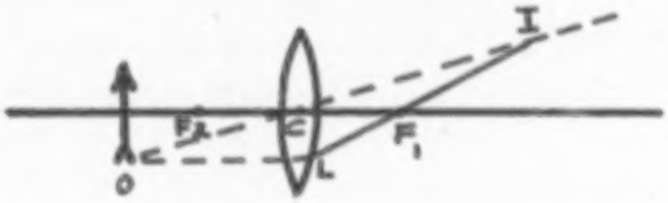
---

d-431

virtual

---

d-401



---

d-371

B
focal point

A·I·R ©1960

(195)

d-358

optical center

principal axis

---

d-388

OCI

image

---

d-418

focus

---

d-448

larger than

---

d-478

$(\frac{1}{5} + \frac{1}{4} =)\ \frac{4}{20} + \frac{5}{20} = \frac{9}{20}$

A·I·R ©1960

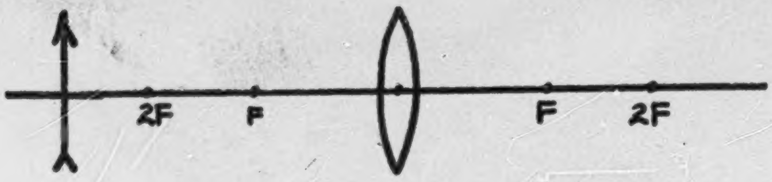
D-491

The object distance, the image distance and the focal length of a lens are related. If we know any two of these measurements, we can find the third. We could find the focal length, providing that we knew * ______ and the * ______.

D-461

An object beyond 2F will produce an image between 1F and 2F on the other side of the lens. Locate and draw the image.

This image is (larger/smaller) ☐ than the object.

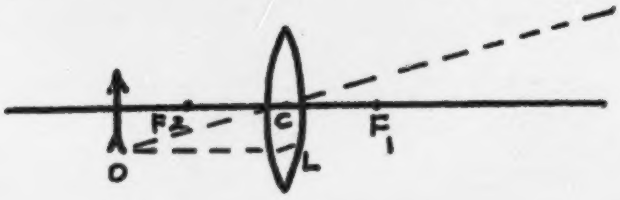


D-431

A virtual image appears to be on the same side of the lens as the object. The image is upright. Since the image appears to be on the same side of the lens as the object, we cannot project a ☐ image on a screen.

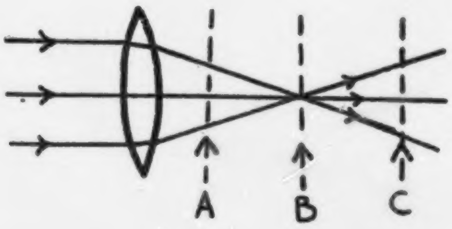
D-401

This drawing shows a secondary axis drawn from point O on the object. Draw in a line, showing the remainder of the path of light ray OL from point O. Label the image point I.



D-371

In the drawing, we could hold up a screen at point A, or point B, or point C. The size of the spot of light will depend on where the screen is held. We will get the smallest spot of light if the screen is held at point $ ______,
which is the * ______.



(961)

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D-359

A secondary axis of a lens is a line which is not perpendicular to both lens surfaces but which does pass through the optical center. The axis in Figure 1 meets the definition of a ☐ axis, but the line in Figure 2 is an example of a ☐ axis.

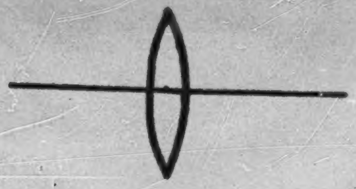


FIG. 1

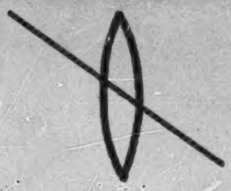
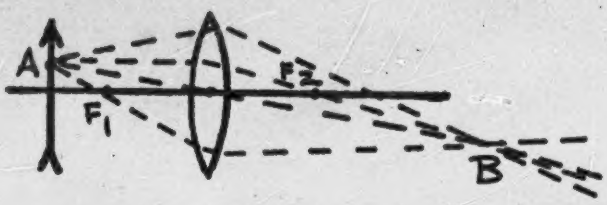


FIG. 2

D-389

An image point is formed where all the light passing through a lens from the corresponding ☐ * meets or focuses. Many rays of light coming from object point A strike the lens. They are all focused at point ☐ $. This point is where the image point corresponding to object point A will appear.

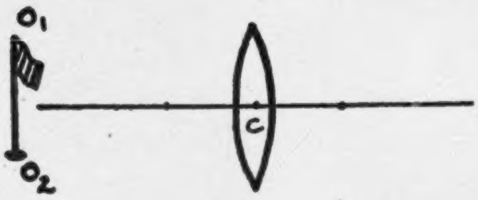


D-419

To get a sharply focused image, all the light coming from any one point on the object must strike the screen at only one image point. There is only one ☐ distance where this will happen for any given object distance.

D-449

In the drawing, a flag pole is some distance from the lens. The image will be inverted and smaller. Locate, and draw in the image.



D-479

Now try this problem, $\frac{1}{3} + \frac{1}{5} = \boxed{\#}$.

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d-490

$(\frac{1}{3} = \frac{1}{d_1} + \frac{1}{6},\ \frac{1}{d_1} = \frac{1}{3} - \frac{1}{6},\ \frac{1}{d_1} = \frac{1}{6},\ d_1 =)$ 6

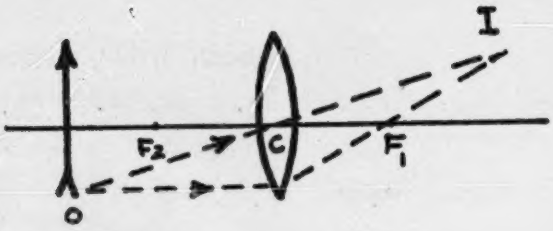
d-460

larger

d-430

virtual

d-400



d-370

convex
diverge
opaque

A·I·R ©1960

d-359

principal

secondary

d-389

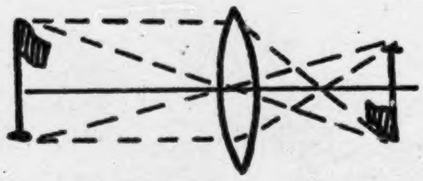
object point

B

d-419

image

d-449



d-479

$(\frac{1}{3} + \frac{1}{5} =) \frac{5}{15} + \frac{3}{15} = \frac{8}{15}$

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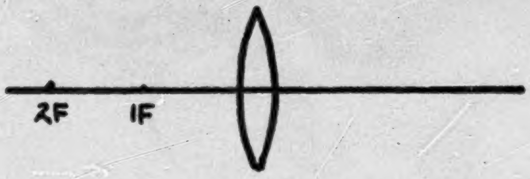
D-490

If f is 3, and d_o is 6, d_i = ☐#.

D-460

The size of the image varies, depending upon the distance between the object and the lens. As the object is moved nearer the lens, the size of the image increases. An object placed near 1F will be ☐ than an object which is placed at 2F.

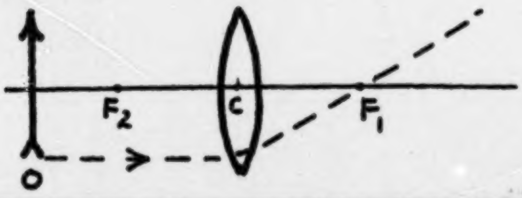


D-430

If an object is very close to the lens, we will see a virtual image instead of a real image. When we look at an object through a magnifying glass, for example, we will see a ☐ image.

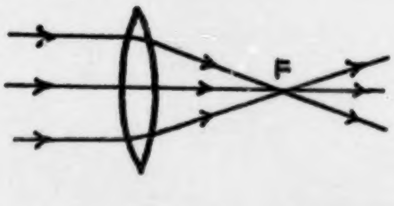
D-400

The drawing shows a parallel light ray passing through focal point F_1. In order to show the formation of an image point, complete the drawing using a secondary axis drawn from point O through the optical center C. Label the image point with the letter I.



D-370

In the drawing, we have used a ☐ shaped lens to converge parallel rays of light. After they reach the focal point F, they begin to (converge/diverge) ☐. We could see a small spot of light by holding up an ☐ screen at the focal point.



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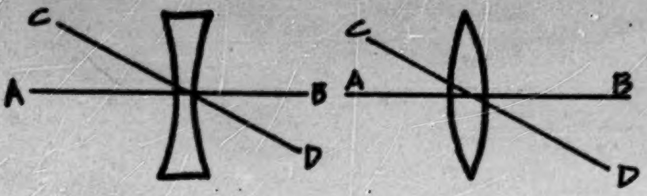
D-360

These drawings show the two different axes (plural of "axis") of a lens. In each figure, line AB is the ______ axis, line CD is a * ______ ______.

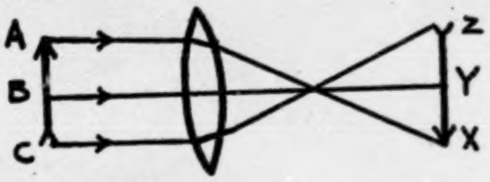


D-390

An image point is formed where the rays from the corresponding object point intersect. While we can draw a large number of light rays coming from any one object point, the point where any two of them cross or ______ is where all the rays will meet.

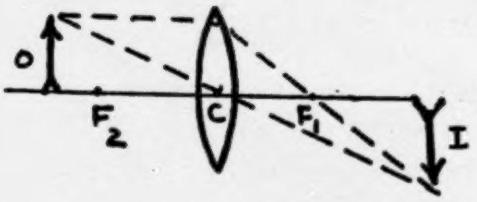
D-420

If we use an arrow as the object, we will get a focused image only when all the light from point A strikes the screen at point $ ______ and all the light from point B strikes the screen at point $ ______.



D-450

In this figure, the object distance is only slightly greater than the focal length. Lines have been drawn which show the image formation of the tip. We can see that, in size, the image is larger than the object when the ** ______ ______ ______.



D-480

To add the reciprocals of two numbers, we first must convert the numbers to their reciprocals, find the lowest * ______ and then add. The sum of the reciprocals of 2 and 3 = # ______.

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d-489

$(\frac{1}{d_1} =)$ $\frac{1}{10}$

$(d_1 =)$ 10

d-459

1F

2F

d-429

inverted

d-399

I

d-369

DE (or, DCE)

AB (or, ACB)

C

F_1 (and) F_2

A·I·R ©1960

d-360

principal

secondary axis

d-390

intersect

d-420

X

Y

d-450

object distance is only slightly greater than the focal length

d-480

common denominator

$(\frac{1}{2} + \frac{1}{3} = \frac{3}{6} + \frac{2}{6} =)\ \frac{5}{6}$

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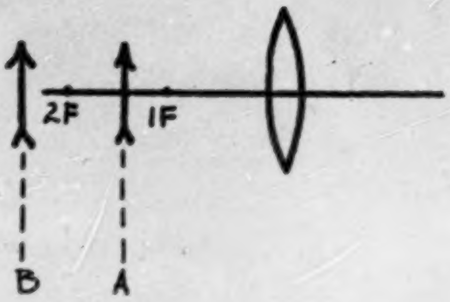
D-489

If $f = 5$ inches and $d_o = 10$ inches, we can substitute these values in the formula $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$ to find d_i. We would have $\frac{1}{5} = \frac{1}{d_i} + \frac{1}{10}$. By subtracting $\frac{1}{10}$ from both sides, we have $\frac{1}{5} - \frac{1}{10} = \frac{1}{d_i}$. Then, $\frac{1}{d_i} = \frac{2}{10} - \frac{1}{10}$, or $\frac{1}{d_i} = \boxed{\#\quad}$. Finally, $d_i = \boxed{\#\qquad}$ inches.

D-459

In this figure, object B is more than 2F from the lens, but object A is between $\boxed{\$\qquad}$ and $\boxed{\$\quad}$.

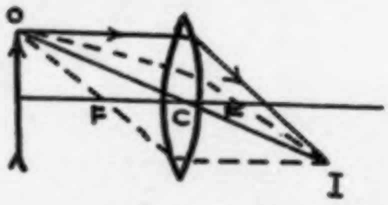


D-429

A real image focused on a screen by a single convex lens will always be upside down; that is, it will be $\boxed{\qquad\qquad}$.

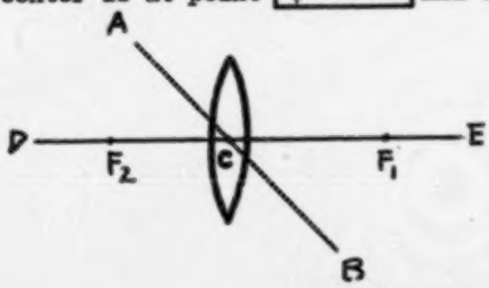
D-399

As shown in the diagram, any two lines could be used to show the formation of point I of the image. However, all the rays from point O which are focused by the lens meet at point $\boxed{\$\quad}$.



D-369

In the drawing, the principal axis of the lens is shown by line $\boxed{\$\qquad}$ and a secondary axis is shown by line $\boxed{\$\quad}$. The optical center is at point $\boxed{\$\qquad}$ and the principal foci are located at $\boxed{\$\qquad}$ and $\boxed{\$\quad}$.



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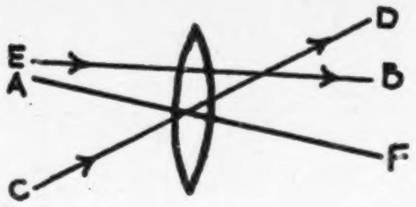
D-361

In the drawing below, lines $ and $ are secondary axes of the lens. Line $ is not a secondary axis because it does not pass through the * of the lens.



D-391

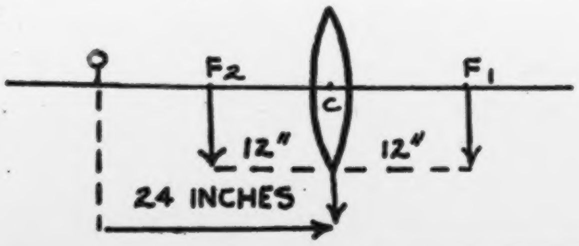
To find the image point corresponding to any object point, we have to draw the paths of only # of the rays of light coming from that object point. The corresponding image point will be where those two rays of light cross or ☐.

D-421

The kind of images we have been talking about so far are real images. A real image is one which is formed where light rays focus after they pass through the lens. If we can focus an image on a screen, we know it is a ☐ image.

D-451

In the drawing, the focal length of the lens is # inches. The object is 24 inches from the lens; that is, the object distance is # inches.



D-481

One reciprocal can be subtracted from another; $\frac{1}{2} - \frac{1}{4} = \frac{2}{4} - \frac{1}{4} = \frac{1}{4}$. In the same way,

$\frac{1}{2} - \frac{1}{3} =$ # = # .

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d-488

$(\frac{1}{f} =) \frac{1}{d_i} + \frac{1}{d_o}$

d-458

two focal lengths from the lens

d-428

inverted

d-398

image
these lines (light rays) meet or intersect

d-368

optical center
secondary axis

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d-361

AF
CD
EB
optical center

d-391

2
intersect

d-421

real

d-451

12
24

d-481

$(\frac{1}{2} - \frac{1}{3} =)\ \frac{3}{6} - \frac{2}{6}\ (=)\ \frac{1}{6}$

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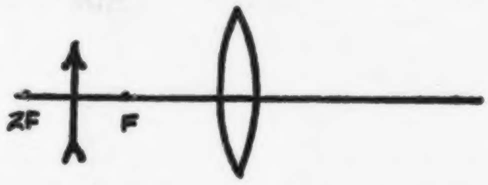
D-488

To find image distance when object distance and focal length are known, we can also use the formula $\frac{1}{f}$ = $ ________.

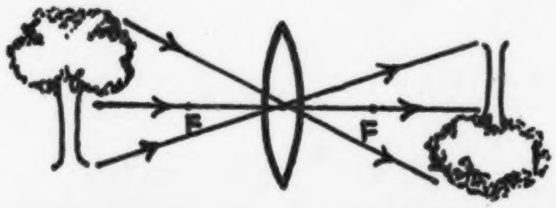
D-458

In the drawing, the focal length is marked "F." Exactly twice this distance away from the lens is the point called 2F. The object is between 1F and 2F; that is, it is more than one focal length from the lens but less than ** ________________.



D-428

If the incoming light passing through a converging lens creates a real image, it will be an inverted or upside down image. In the drawing, the image of the tree will be both real and ________.

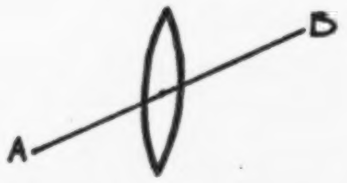


D-398

Two lines coming from an object point are required to locate the corresponding ________ point. You have seen how a line parallel to the principal axis and a line representing a secondary axis can be used. The image point is located where ** ________________ after passing through the lens.

D-368

A secondary axis may be in any position, so long as it passes through the * ________ of the lens and is not perpendicular to the lens. Line AB is therefore a * ________.



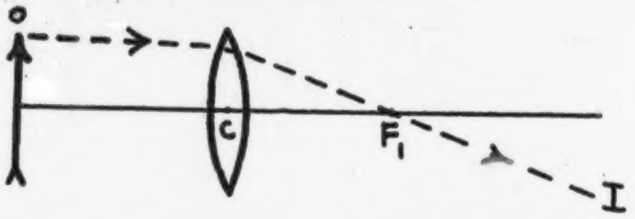
A·I·R ©1960

D-362

The point where parallel rays converge after they pass through a lens is called the ☐ point. The distance between this point and the optical center is called the ☐ length.

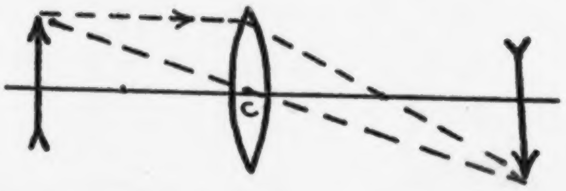
D-392

Earlier, we learned that all rays of light parallel to the principal axis would converge at the focal point. An incoming parallel ray of light from object point O, according to this rule, will pass through F_1, the ☐ * of the lens.



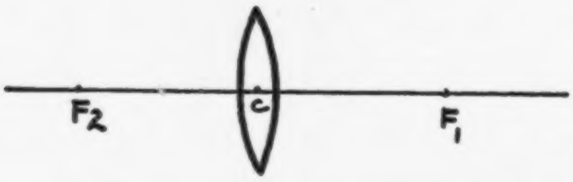
D-422

This drawing shows the formation of a ☐ image. We know it is a ☐ image because each image point is formed where the rays of light leaving a given object point ☐ .



D-452

In the figure, the points F_1 and F_2 are the ☐ * of the lens. We use the symbols F_1 and F_2 as an easy way to identify either ☐ * .



D-482

Sometimes, when we subtract one reciprocal or fraction from another, we get a negative or minus answer. For instance, $\frac{1}{4} - \frac{1}{3} = \frac{3}{12} - \frac{4}{12} = -\frac{1}{12}$. In the same way, $\frac{1}{5} - \frac{1}{3} =$ ☐ # = ☐ #

A·I·R ©1960

d-487

(f =) 1.2 (inches)

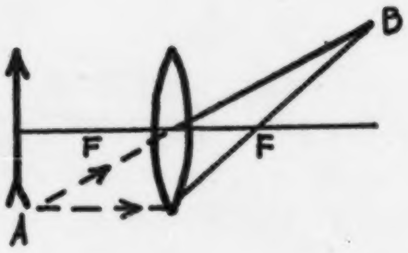
d-457

one focal length (or, 1F)

d-427

bottom

d-397



d-367

opaque

transparent

A·I·R ©1960

d-362

focal
focal

d-392

focal point (or, principal focus)

d-422

real
real
intersect (or, meet, focus)

d-452

focal points
focal point

d-482

$(\frac{1}{5} - \frac{1}{3} =)\ \frac{3}{15} - \frac{5}{15}\ (=)\ -\frac{2}{15}$

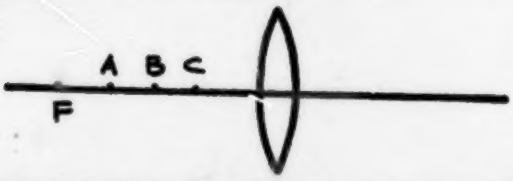
A·I·R ©1960

D-487

If d_1 = 2 inches and d_o = 3 inches, f = [#] inches.

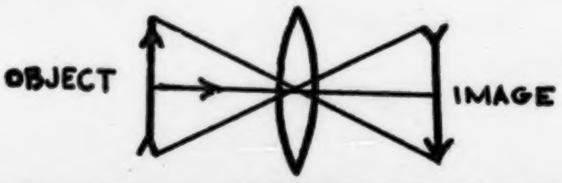
D-457

An object can, of course, be placed at any distance from the lens. It is convenient to speak of an object placed between the focal length and the lens as an object at "less than 1F." In the drawing, the object distances A, B, and C are all placed at less than [*].



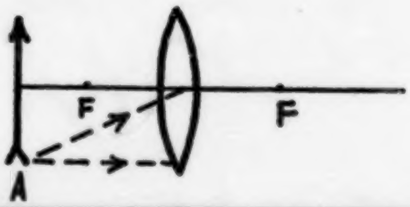
D-427

In our drawings which showed how an image was formed, the object was upright; that is, the arrow pointed toward the top of the page. The image formed by a convex lens is inverted; that is, the arrow points toward the [ ] of the page.



D-397

No matter which object point we select, we can find the corresponding image point using lines to represent the paths of two light rays coming from that point. Complete the lines representing light rays coming from point A on the object to show how they meet. Label the image point with the letter B.



D-367

We can only see a real image when light rays fall on an [ ] screen. This kind of screen is made of material which is not [ ].

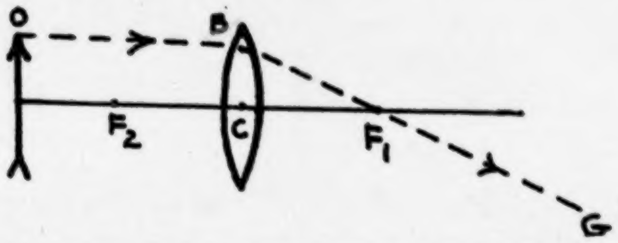
A·I·R ©1960

D-363

Although light rays may converge after passing through a transparent medium such as a lens, they do not stop at the focal point. They continue beyond this point. The rays of light will continue until they come to an object which is not [ ]; that is, a surface which does not allow light to pass through.

D-393

We know that a convex lens will cause parallel rays of light to pass through the [*]. Line OBG is drawn according to this rule. The image of the arrow tip, point O, will therefore be located somewhere along this line.



D-423

If, after the light rays from an object point pass through the lens, they converge to form a single image point behind the lens, the kind of image is known as a [*].

D-453

When a number is placed behind a symbol, as in F_2, this is another way of saying "focal point number two." On the other hand, when the number is placed in front of the symbol, this is a mathematical way of saying "multiply by." For example, 2F means "F multiplied by [#]."

D-483

In many cases, when we do a problem involving the reciprocals of numbers, we must convert the answer back into a whole number. For instance, if $\frac{1}{A} = \frac{1}{7}$, then $A = 7$ and if $\frac{1}{R} = \frac{1}{10}$, $R =$ [#].

A·I·R ©1960

d-486

$(\frac{1}{f} =)\ \frac{3}{6}$

$(f = \frac{6}{3} =)$ 2 inches

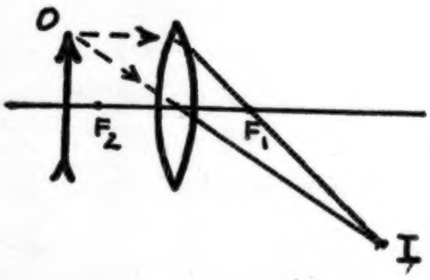
d-456

lens

d-426

image

d-396



d-366

opaque

image

A·I·R ©1960

(215)

d-363

transparent

d-393

focal point (or, principal focus)

d-423

real image

d-453

2

d-483

10

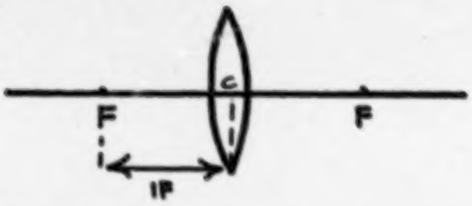
A·I·R ©1960

D-486

The formula for finding f, knowing d_i and d_o, is $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$. If d_i equals 3 inches and d_o equals 6 inches, then $\frac{1}{f} = \frac{1}{3} + \frac{1}{6}$, or, $\frac{1}{f} = \boxed{\#}$. To find f, we must invert the fraction and then divide the numerator by the denominator, or f = $\boxed{*}$.

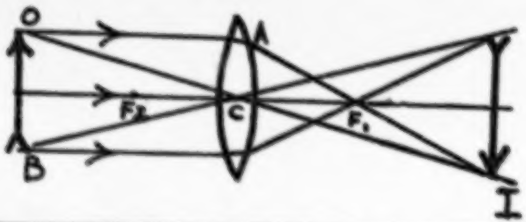
D-456

When we use the term 1F, we mean a certain distance from the lens. If we say "we place an object at 1F," for example, we mean that the object is placed one focal length from the ______.



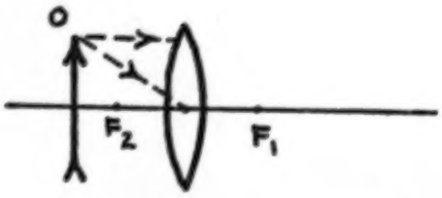
D-426

Real images are always inverted. To understand how images are turned upside down, follow the line from O to A to F_1 to I. O is the object point at the tip of the arrow. Point I is the ______ point which corresponds to that object point.



D-396

Complete the lines representing light rays coming from point O on the object to show where they meet or intersect. Label this point with the letter I.



D-366

To see an image at the focal point, we must use an ______ screen held at that point. If the screen is not there, the light rays will continue to travel, and we will not be able to see an ______.

(912)

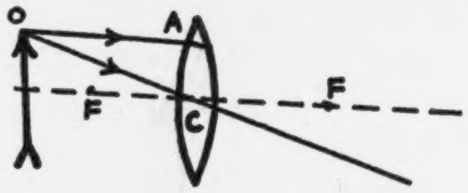
A·I·R ©1960

D-364

In order to see parallel rays of light converge to a spot at the focal point, we must use a screen made of material which is not [ ] . The screen must be placed at the [*] to see the spot.

D-394

The image point corresponding to any object point is located where any two lines, representing light rays coming from the object point and passing through the [ ], join or intersect. It is often convenient to use the two lines shown in this figure: line OA, which is [ ] to the principal axis and line [$] which is a secondary axis.

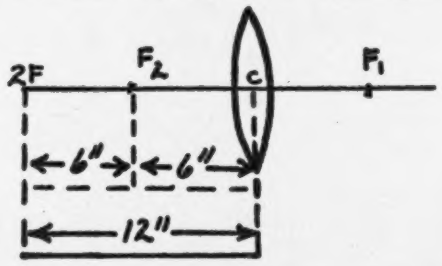


D-424

A real image formed by a lens can only be seen if we project it on to a screen. We cannot see [ ] images by placing our eye at an image point. The image projected on a screen by a movie projector is a [*].

D-454

In the drawing, F is the focal point, and the distance between the focal point and the optical center can be measured. If the focal length of a lens is six inches, then two times the focal length, or 2F, could be expressed in inches as [#] inches.



D-484

If $\frac{1}{P} = \frac{5}{10}$, then $P = \frac{10}{5}$, or P = 2. If $\frac{1}{M} = \frac{5}{12}$, then M = [#], or, M = [#].

A·I·R ©1960

d-485

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

d-455

12
12

d-425

screen (or, opaque surface)
eyes

d-395

image
bent (or, refracted)
focal point (or, principal focus)

d-365

opaque

A·I·R ©1960

⑲

d-364

transparent
focal point

d-394

lens
parallel
OC

d-424

real
real image

d-454

12

d-484

(M =) $\frac{12}{5}$
(M =) 2.4

A·I·R © 1960

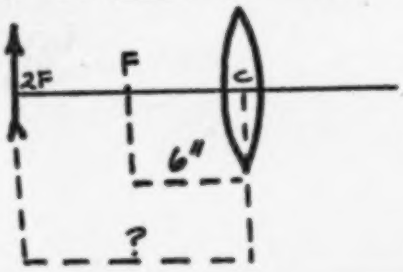
D-485

The reciprocal of focal length, or $\frac{1}{f}$, is equal to the sum of the reciprocals of the image distance and object distance. In symbols, the formula would be written as

$\frac{1}{f}$ = [$].

D-455

For convenience, we might say that an object is placed at 2F. "2F" means "two times the focal length." In the drawing, the focal length is six inches. The object at 2F is two focal lengths, or "two times the focal length" from the lens, or [#] inches from the lens. The object distance is [#] inches.

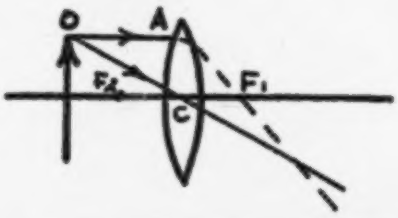


D-425

A real image is one that can be projected on to a [ ]. We cannot see real images directly with our [ ].

D-395

By extending lines OA and OC until they meet or intersect, we can find the [ ] point corresponding to object point O. Since line OC passes through the optical center, it is not [ ] as it passes through the lens. Line OA, however, is bent. Since it was parallel to the principal axis, it will pass through the [*].



D-365

A material which is not transparent is called opaque (say, "oh-pake"). In order to see an image, we allow the light to fall on an [ ] surface after it has passed through a lens.

A·I·R ©1960

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

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UNIT 5

ABERRATIONS, THE EYE, AND MAGNIFICATION

Steps D-495 through D-646

BEGIN UNIT HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

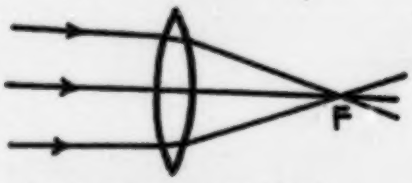
UNIT ENDS HERE

D-495

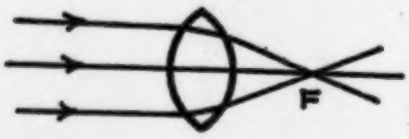
A lens cannot do everything we want it to do. In some ways, lenses are limited in the way they refract light. The effects of any such limitation are called aberrations (pronounced ab-er-ay-shuns). Even a carefully made lens produces some ☐.

D-527

A glass lens has a fixed shape and a fixed focal length. The crystalline lens can change shape, and therefore has a variable ☐ *. When it is thin, it has a ☐ focal length, and when it is thick, it has a ☐ focal length.



LONG FOCAL LENGTH



SHORT FOCAL LENGTH

D-559

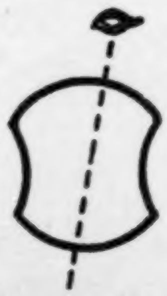
The image seen through a concave lens is (real/virtual) ☐, (upright/inverted) ☐, and (smaller/larger) ☐ than the object.

D-591

We learned earlier that the image from an object placed more than 2F from the lens was smaller, real and ☐.

D-623

The Covington magnifier (named for the man who first made this style) is really a glass bead with the edges cut off to form a cylinder. It has grooves cut to reduce aberration. In actual use, we place the object very close to the lens (less than 1F). The image we see is (larger/smaller) ☐ in size than the object.



A·I·R ©1960

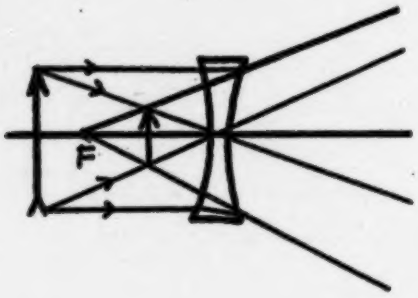
d-622

acted as a lens to magnify the olives

d-590

object
ocular

d-558



d-526

crystalline
muscles

A·I·R ©1960

227

d-495

aberrations

---

d-527

focal length
long
short

---

d-559

virtual
upright
smaller

---

d-591

inverted

---

d-623

larger

A·I·R ©1960

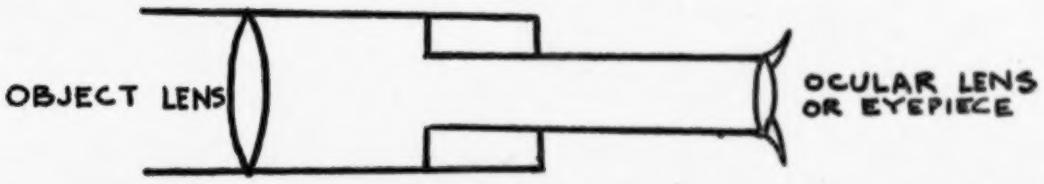
D-622

A bottle of olives sitting on a store shelf often seems to contain huge olives, which are only standard size when seen out of the bottle. The curved glass and the liquid in the bottle have ** ________.

D-590

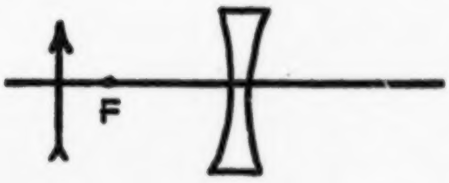
A simple refracting telescope is shown in the figure. The larger lens, which is pointed toward the object, is known as the object lens. The eyepiece is called the ocular lens. A basic telescope consists of an

________ lens and an
________ lens.



D-558

Draw in an image for this object, seen through a concave lens.



D-526

In the accommodation process of the human eye, the shape of the * ________ is changed by the ciliary ________ so that the eye can focus on near or distant objects.

A·I·R ©1960

D-496

Aberrations are the result of the way light behaves; they are not necessarily due to defects in the construction of the lens. By knowing what causes these ☐, we can make special modifications in the way a lens is constructed which will help to overcome them.

D-528

If the small ciliary muscles are not operating properly, the focal length of the crystalline lens cannot change appropriately. We would say that this eye had lost its power of ☐. This often happens as individuals grow older; the ☐ lens begins to harden, and the ciliary muscles are then no longer able to change the ☐ of the eye.

D-560

So far, you have learned to locate the image of an object placed more than one focal length from a convex lens. An object can also be placed less than one focal length from a convex lens. The image of an object placed between F and the lens will be magnified, which means that the image will be virtual instead of real, and that it will be (larger/smaller) ☐ than the object.

D-592

The object lens of a telescope receives light from very distant objects. The distance is always more than 2F or twice the focal length. For this reason, the first image formed inside a telescope is always ☐, ☐, and ☐.

D-624

Some pocket magnifiers are called doublets or triplets, meaning that two or three lenses are combined. The additional lenses may be used for several reasons, but often they are added to increase the magnification. In such cases, all the lenses are used as ☐.

A·I·R ©1960

d-621

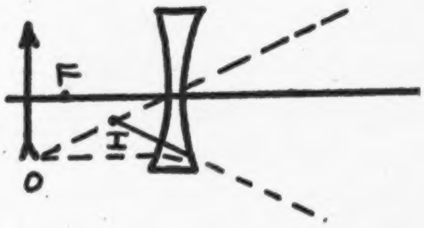
magnified

d-589

refracting

convex

d-557



d-525

accommodation

A·I·R ©1960

231

d-496

aberrations

d-528

accommodation
crystalline
focus

d-560

larger

d-592

real
inverted
smaller

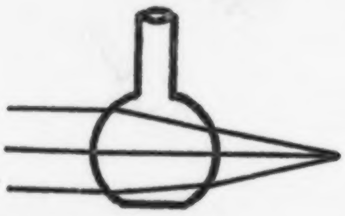
d-624

magnifiers

A·I·R ©1960

D-621

We could fill a round chemistry flask with water. Rays of light passing through the flask would converge beyond the flask. This arrangement would act as a simple lens; the image of an object placed close to the lens will be ☐.

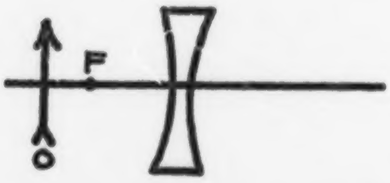


D-589

A telescope using lenses is known as a refracting telescope. The simplest ☐ telescope is made with two ☐ shaped lenses.

D-557

Find the image point corresponding to object point O in this figure. Label it I.



D-525

One man may see highway signs clearly, although he cannot see the small letters in a telephone directory. Another man may have excellent vision at close range, but have difficulty seeing distant objects. Both eye defects are examples of poor ☐.

A·I·R ©1960

D-497

The effects of the limitation of lenses on the quality of the images they produce are called ________.

D-529

Individuals who have normal vision have normal accommodation. Some people are "far" sighted and other are "near" sighted. In either case, such vision is due to faulty ________ and it results in images on the retina which are out of ________.

D-561

An object placed at less than one focal length from a convex lens will be magnified; that is, the size of the ________ will appear larger than the size of the actual object. A magnified image is not the same as an enlarged image. We get an enlarged image if the object is placed between 1F and 2F, but we get a ________ image if the object is placed less than one * ________ from a convex lens.

D-593

The object lens of a telescope produces a small, inverted image in the telescope. We can now see the reason for the use of a second lens, the eyepiece, which is a magnifying lens. We want an enlarged image to reach our eye, so a magnifying lens, called the ________ lens, is used to enlarge the image produced by the object lens.

D-625

A device or apparatus which uses lenses to magnify small, nearby objects is called a microscope. An instrument which consists of a single convex lens, and often some attachment to adjust object distance, is called a simple ________.

A·I·R ©1960

d-620

magnify
object

d-588

magnifies (or, enlarges)

d-556

intersects (or, meets)
I

d-524

accommodation

A·I·R ©1960

(235)

d-497

aberrations

d-529

accommodation
focus

d-561

image
magnified
focal length

d-593

ocular

d-625

microscope

A·I·R ©1960

D-620

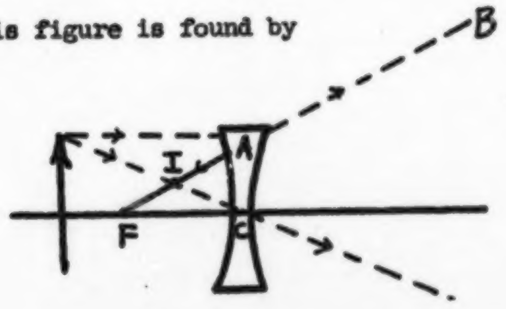
The famous Dutch biologist, Van Leeuwenhoek, (pronounced Van Lay-van-hook) was one of the first scientists to experiment with small objects viewed through a magnifier. Some stories say that he used a small glass bead to ☐ the size of the ☐ that he wanted to inspect.

D-588

The second lens in a simple telescope is also a convex lens. This lens increases the size of, or ☐, the image.

D-556

The image point corresponding to object point O in this figure is found by extending line AB back to where it ☐ with line OC. This point has been labeled [$].



D-524

A person whose eyes have the ability to focus readily on both near and distant objects has a normal accommodation process. On the other hand, an individual who cannot focus clearly does not have the normal power of ☐.

A·I·R ©1960

D-498

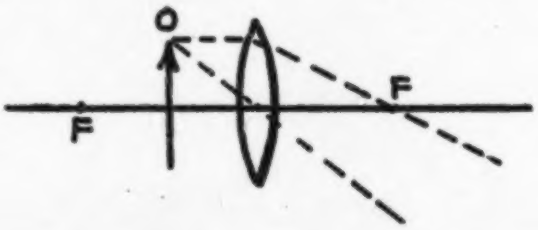
A lens which has perfectly spherical surfaces will not converge quite all of the incoming parallel rays to a single point. These characteristic limitations of spherically surfaced lenses are known as spherical [ ].

D-530

Nearsightedness is a condition of the eye in which only nearby objects are clearly focused. When distant objects cannot be clearly focused on the retina, the individual has an eye condition called myopia or [*].

D-562

In the drawing, the object is shown inside the focal point, meaning that the image will be [ ]; that is, made larger. Note that, in this case, the secondary axis and a parallel line from the object point O, which we have used before to show image formation, do not [ ] on the side of the lens opposite the object.



D-594

A telescope which has only two lenses will produce an enlarged but inverted image. The [ ] lens magnifies the small inverted image produced by the [ ] lens.

D-626

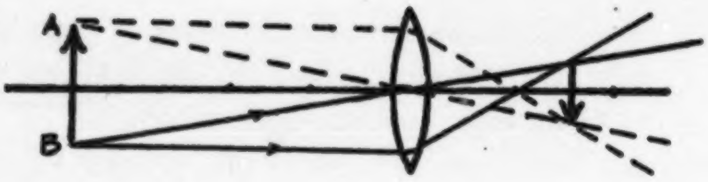
An optical instrument which has only one lens (such as a small pocket magnifier) is a simple microscope. Using the dictionary term "compound," which means to "combine," we can call a microscope, which has more than one magnifying lens, a [ ] microscope.

A·I·R ©1960

d-619

magnified

d-587



d-555

focal point

d-523

accommodation

A·I·R ©1960

d-498

aberrations

d-530

nearsightedness

d-562

magnified
converge (or, focus, meet, intersect)

d-594

ocular (or, eyepiece)
object

d-626

compound

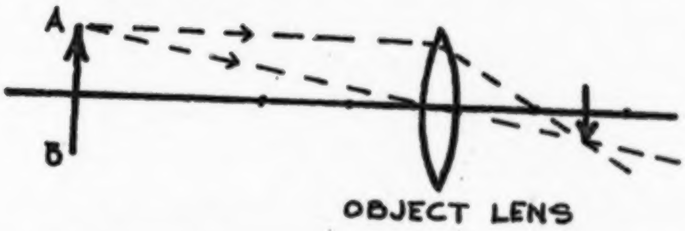
A·I·R ©1960

D-619

A glass bead or a drop of water can be used as a simple magnifying lens. A spherical glass bead, in fact, makes a fairly good magnifier. The image of an object placed close to a clear glass bead would be ________ by this lens.

D-587

This is an object lens of a telescope. The path of light has been drawn for the light rays from point A. Draw in the path of rays B. In this figure, the object is small and close to the lens. Objects we look at through a telescope, of course, are much larger and much farther from the lens.



D-555

Lines representing the diverging of light rays which entered a concave lens parallel to the principal axis are drawn as if they were straight lines originating at the * ________ of the lens.

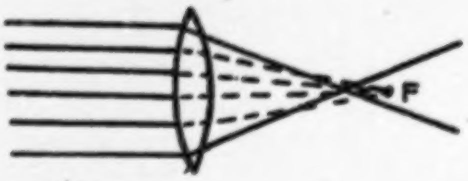
D-523

The ciliary muscles change the shape of the crystalline lens in a process called accommodation. The ability of the human eye to focus at varying distances is the result of this ________ process.

A·I·R ©1960

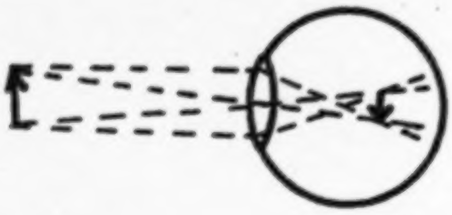
D-499

In a diagram, we generally show all parallel rays of light focusing or ________ at point F. Actually, however, a lens with perfectly spherical surfaces will bend a few of the rays, those that pass through the lens near its edge, incorrectly. These rays do not meet the other parallel rays at the * ________.



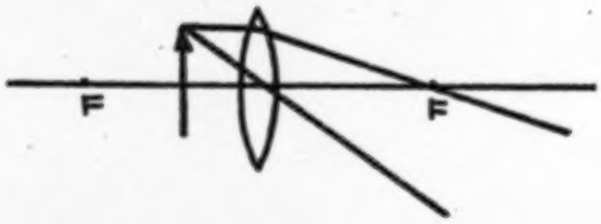
D-531

An individual cannot see distant objects clearly when the rays of light from those objects converge at a point in front of the retina. His visual defect is known as myopia; he is said to be myopic or ________.



D-563

In the figure, the two lines we usually use to find an image diverge rather than intersect behind the lens. The lines show that no real image is formed on the side of the lens opposite the object when an object is placed ** ________ ________.



D-595

A magnifying lens enlarges an image, but does not invert the image. In a telescope, the small, inverted image from the object lens is enlarged by the eyepiece, but the image is still ________ when we see it.

D-627

A compound microscope uses more than one magnifying lens. Both the object lens and the eyepiece, or ocular lens, are used for ________. This is different than the telescope, where only the ________ is used for magnification.

A·I·R ©1960

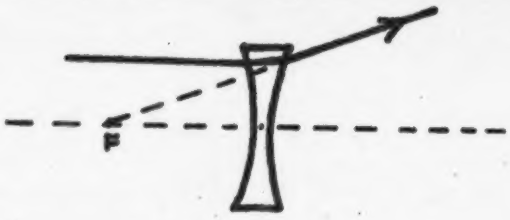
d-618

one focal length
magnifiers (or, magnifying lenses)

d-586

convex

d-554



focal point

d-522

focal length

A·I·R ©1960

d-499

converging (or, meeting)
focal point

d-531

nearsighted

d-563

inside the focal point (or, between the lens and the focal point)

d-595

inverted

d-627

magnification
ocular (or, eyepiece)

A·I·R ©1960

D-618

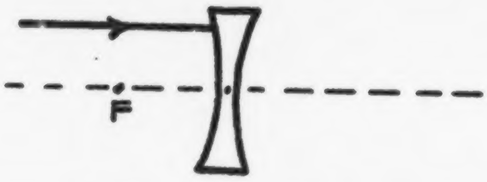
Magnification occurs when an object is placed less than * ______ away from a convex lens. A lens used in this way is called a magnifying lens or a magnifier. All ______ are made of convex lenses.

D-586

In constructing a telescope, the first lens selected should cause light to converge or focus at a particular spot, so a ______ shaped lens is required.

D-554

This figure shows a parallel ray of light entering a concave lens. Draw a line to show the direction in which it will leave the lens. If this line were extended back in a straight line, it would pass through the * ______ ______ of the lens.



D-522

Different shaped glass lenses have different focal lengths. When the ciliary muscles pull on the crystalline lens, they change its shape. This changes the * ______ ______ of the lens to permit a sharp focus regardless of the distance of the object.

A·I·R ©1960

D-500

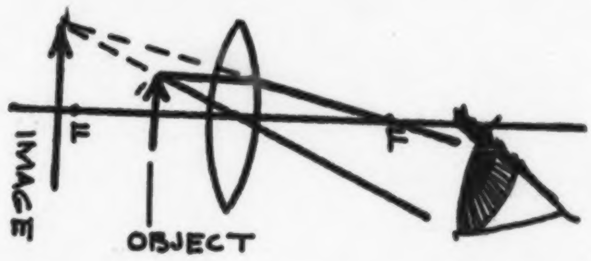
The center of a lens is more likely to refract light rays properly since spherical aberration is greatest at the edges of the lens. This is why many inexpensive cameras use only the center of the lens where the image is clear and sharp. Even though a lens may have ☐ * near its edges, it can be used in many applications if no light is permitted to pass through a lens near its outer ☐.

D-532

A myopic individual is one who sees ☐ objects most clearly. The condition of nearsightedness is technically known as ☐.

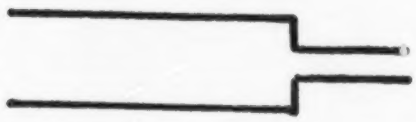
D-564

The image seen when we look through a convex magnifying glass is a virtual image. The image can be located by extending the lines coming to our eye from the object. The image will be (larger/smaller) ☐ than the object.



D-596

Here is a diagram of a two-lens telescope tube or case. Draw in properly shaped lenses and label them correctly.



D-628

We use a telescope to magnify the apparent size of objects which are far away from the lens. A microscope is used to ☐ the size of objects placed ☐ the lens.

A·I·R ©1960

d-617

prism

d-585

telescope

d-553

diverge
focal point

d-521

focus

A·I·R ©1960

d-500

spherical aberrations
edges

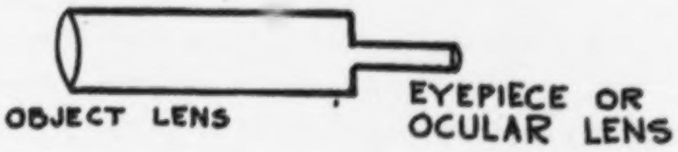
d-532

close (or, nearby)
myopia

d-564

larger

d-596


OBJECT LENS
EYEPIECE OR
OCULAR LENS

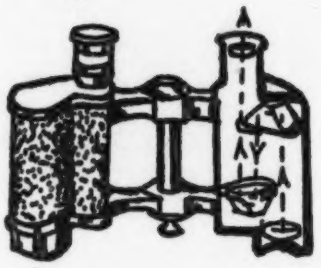
d-628

magnify (or, increase)
near

A·I·R ©1960

D-617

Prism binoculars are actually much like a pair of short telescopes, one for each eye. Each tube has an objective (or object lens) in front, and an eyepiece (or, ocular lens) at the rear. Between these two converging lenses, a pair of totally reflecting prisms invert the image and increase the length of the path of light between the lenses. An upright, magnified image is produced by ☐ binoculars.

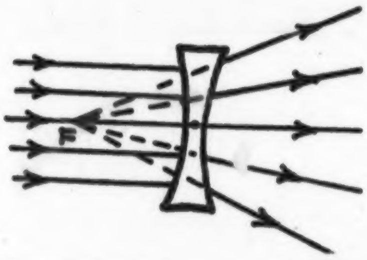


D-585

A **telescope** is an optical instrument which permits us to see distant objects more clearly. It performs two separate tasks. It collects the almost parallel rays of light from a distant object, focusing them as a clear image at one particular spot. A second task is the **enlargement or magnification** of this image. At least two separate lenses are needed in a ☐ to perform the different tasks.

D-553

Light rays which enter a concave lens parallel to the principal axis ☐ as they are refracted by the lens. These diverging rays all appear to originate at F, the ☐ of the concave lens.



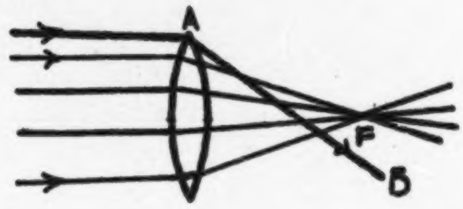
D-521

Tiny muscles connected to the eye (the ciliary muscles) can stretch the crystalline lens or let it contract it for proper **focus**. Whether an object is near or far away, these muscles adjust the lens to keep a clear, sharp image in ☐ on the retina.

A·I·R ©1960

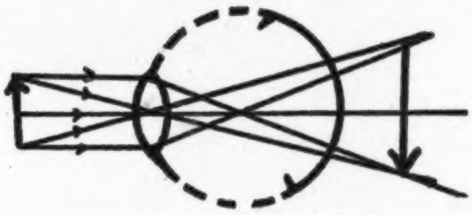
D-501

A limitation due to the spherical shape of a lens face is shown in this figure. The parallel rays of light do not all meet at the focal point after passing through the lens. This is known as * ________. The ray represented by line $ ____ passes through the lens near its ________; it does not ________ at F.



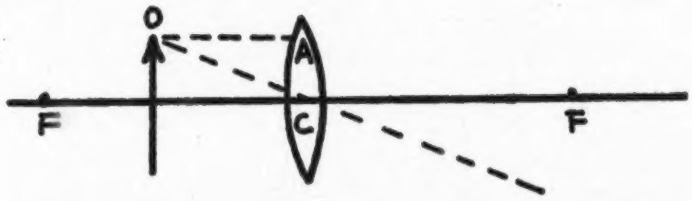
D-533

Hypermetropia, or farsightedness, is a condition in the eye which causes light to focus behind the retina. When nearby objects cannot be clearly focused on the retina, the individual has an eye condition called hypermetropia or ________.



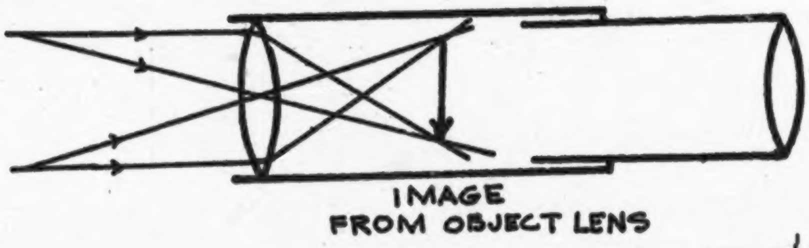
D-565

The procedure for locating an image point corresponding to an object point, when the object distance is less than one focal length, is similar to that used for finding the image point for an object seen through a concave lens. You should draw line OA, which represents a ray ________ to the principal axis and line OC, which is a * ________.



D-597

The figure shows the image formed inside a telescope by the converging of light rays after they pass through the object lens. This image serves as the object for the ocular lens; that is, the ________ produced by the first lens is the ________ viewed through the second lens.



D-629

A telescope's first lens produces a small inverted image which is magnified by another lens (or, eyepiece). All the lenses in a microscope magnify the image. The second lens, or eyepiece of a microscope, ________ an image which is already (larger/smaller) ________ than the original object.

A·I·R ©1960

d-616

increases
decreases

d-584

$(\frac{1}{f} = \frac{1}{6} - \frac{1}{18} = \frac{3}{18} - \frac{1}{18} = \frac{2}{18} =)\ \frac{1}{9}$

$(f =)\ 9$

d-552

secondary axis
diverge

d-520

retina
shape
focal

A·I·R ©1960

(261)

d-501

spherical aberration
AB
edge
converge (or, focus, join the other rays)

d-533

farsightedness

d-565

parallel
secondary axis

d-597

image
object

d-629

magnifies
larger

A·I·R ©1960

D-616

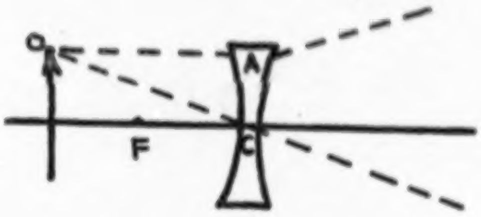
The $\frac{F}{f}$ for three telescopes are $\frac{60}{3}$, $\frac{120}{3}$, and $\frac{60}{1}$. You can see that magnifying power increases as either the focal length of the object lens ☐ or as the focal length of the ocular lens ☐.

D-584

When $d_o = 6$ and $d_i = -18$, $\frac{1}{f} =$ # and $f =$ #.

D-552

The line drawn from point O through point C is called a * . A ray of light which passes through the optical center of a lens is not refracted; it does not change direction. Rays parallel to the principal axis of a convex lens will fan out, however; that is, they will ☐.



D-520

We know that a short-radius converging lens has a short focal length and a longer-radius converging lens has a longer focal length. Since the crystalline lens in a human eye can change shape, becoming either thick or thin, it can focus both distant and nearby objects on the ☐. The crystalline lens in the tye can change its ☐ when necessary to produce different ☐ lengths.

A·I·R ©1960

D-502

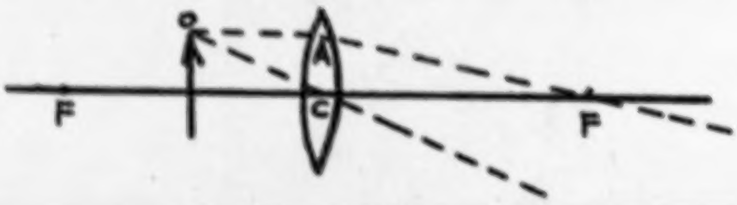
No spherical lens is ever absolutely perfect. We can cover up the edges of a lens so that a very large percentage of light rays which pass through the lens converge exactly as we want them to do. In this way we can reduce the * ______. We can also reduce the * ______ somewhat by changing the shape of a lens slightly, making the curvature less spherical near the edges.

D-534

An individual cannot see nearby objects clearly if the rays which furnish the image converge at a point behind the retina. His visual defect is hypermetropia; he is said to be hypermetropic or ______.

D-566

Since line OA is parallel to the principal axis, it will pass through the * ______ ______ after it leaves the lens. All parallel rays of light will ______ at point F after they leave a convex lens.



D-598

When two lenses are used together as they are in a telescope, the image produced by the first lens serves as the ______ for the second lens.

D-630

The object distance of a telescope is generally very large; the object distance of a microscope is ______.

A·I·R ©1960

d-615

magnifying power
40

d-583

6

d-551

parallel
optical center

d-519

closer to
decreases

A·I·R ©1960

(255)

d-502

spherical aberrations
spherical aberrations

d-534

farsighted

d-566

focal point
converge (or, meet)

d-598

object

d-630

small (or, short)

A·I·R ©1960

END OF UNIT

D-615

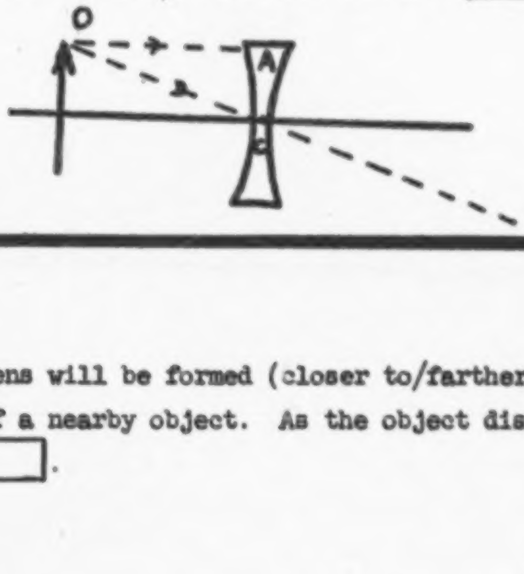
Usually the symbol "X" is used to indicate the magnifying power of a lens. A 40 X lens means a lens with a ☐ * of ☐ #.

D-583

The formula $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$ can be used to find the focal length of a lens even when d_i is a minus number. For instance, if $d_o = 3$ inches and $d_i =$ minus 6 inches, $\frac{1}{f} = \frac{1}{3} + \frac{1}{(-6)}$. This is the same as writing $\frac{1}{f} = \frac{1}{3} - \frac{1}{6}$, or, $\frac{1}{f} = \frac{2}{6} - \frac{1}{6} = \frac{1}{6}$. Thus, f = ☐ # inches.

D-551

To find the image point corresponding to an object point of an object seen through a concave lens, draw one line, OA, from the object point to the lens which is ☐ to the principal axis, and another line, OC, from the object point through the ☐ * of the lens.



D-519

The image of an object far from a lens will be formed (closer to/farther from) ☐ the lens than the image of a nearby object. As the object distance increases, the image distance ☐.

A·I·R ©1960

D-503

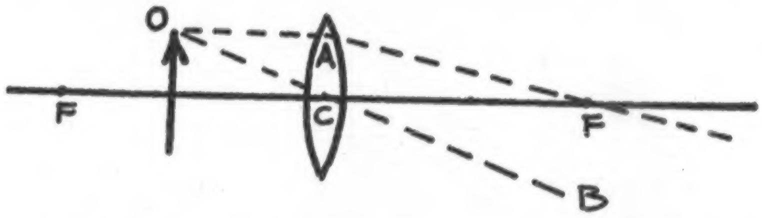
We can correct for spherical aberration by using only the center of the lens, by reshaping the lens, or by placing several lenses together. For example, many expensive cameras have seven lenses of differing indices of refraction and shape. This too will reduce the amount of * ________________.

D-535

A hypermetropic individual is one who sees * ________________ most clearly. The condition of farsightedness is technically known as ________________.

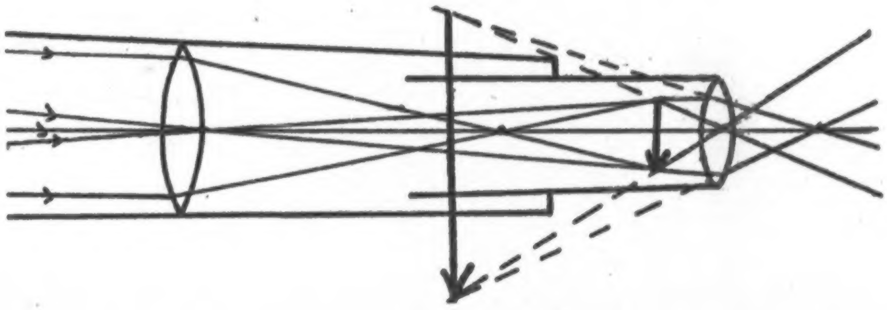
D-567

Lines AF and CB diverge as they leave the lens. This means they will never ________ to form an ________ point on that side of the lens.



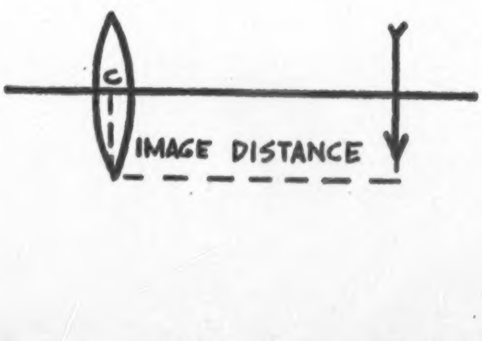
D-599

The magnifying or ocular lens in a telescope produces an enlarged, virtual image of the image produced by the ________ lens as shown in the figure.



D-631

The term image distance is a familiar method of referring to the measurement along the principal ________ between the image and the optical center of the lens. The symbol, d_i, (pronounced dee-sub-eye) stands for * ________________.



A·I·R ©1960

d-646

virtual

d-614

40

d-582

$(\frac{1}{6} = \frac{1}{4} + \frac{1}{d_1}, \frac{1}{d_1} = \frac{1}{6} - \frac{1}{4} = \frac{2}{12} - \frac{3}{12} = - \frac{1}{12}$, and $d_1 =$) -12

minus
virtual

d-550

upright

d-518

farther from
lens

A·I·R ©1960

d-503

spherical aberration

d-535

distant objects
hypermetropia

d-567

intersect (or, meet)
image

d-599

object

d-631

axis
image distance

A·I·R ©1960

D-646

The image produced by a microscope, regardless of which lens we are considering, is always a (real/virtual) ☐ image

D-614

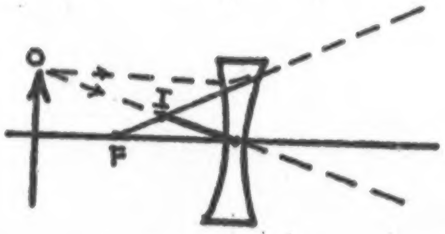
The magnification of a telescope is written as $\frac{F}{f}$, but we can think of it as the number of times larger an object appear to be when viewed with a telescope. An object which appears to be 40 times larger means that the magnifying power of the telescope is [#].

D-582

If d_o is 4 and f is 6, d_i = [#]. Whenever d_o is less than f, d_i will be a ☐ number. In this case, we have a ☐ image.

D-550

The image seen through a concave lens is a virtual image. The image seen through a concave lens can be located by extending the lines representing rays of light leaving the lens back toward the focal point. The image will be (upright/inverted) ☐.



D-518

For a near by object, the film must be (closer to/farther from) ☐ the lens than if the object were farther away. In a camera, we change the image distance by "focusing" the camera; that is, by moving the lens closer to or farther away from the ☐.

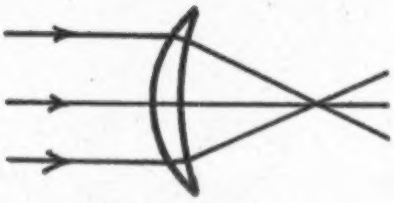
A·I·R ©1960

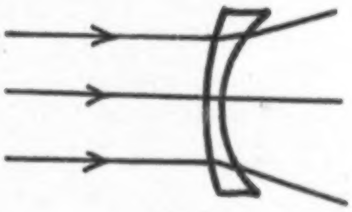
D-504

The principal focus is the point where most parallel rays of light will come together after passing through a converging lens. Some parallel rays passing through a lens with a spherical aberration will ** ________________.

D-536

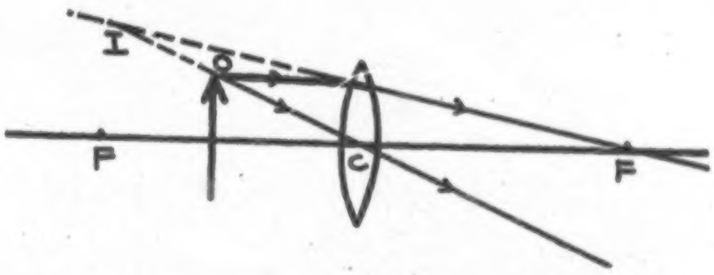
A considerable amount of a person's loss of accomodation can be corrected with eyeglasses. Most eyeglasses are made of meniscus or crescent-shaped lenses. As the figures show, these lenses can be made to either ________ or ________ parallel rays of light.





D-568

The image point corresponding to an object point of an object between 1F and a convex lens is found by extending the lines representing rays leaving the lens back in a straight line to the point from which they seem to originate. That point in this figure has been labeled $ ________.



D-600

The object lens focuses the almost parallel rays of light coming from a distant object so that they can be ________ by the ocular lens. This first step is necessary since magnification will only occur when the object is less than one * ________ away from the lens.

D-632

The object distance is measured along the * ________________ between the ________ and the * ________________. The symbol, d_o, (pronounced dee-sub-oh) stands for the * ________________.

A·I·R ©1960

d-645

300

d-613

75

5

15

d-581

$(\frac{1}{d_1} = \frac{1}{9} - \frac{1}{3} = \frac{1}{9} - \frac{3}{9} =) - \frac{2}{9}$

$d_1 = -\frac{9}{2} = -4.5$ (or, - 4 1/2)

d-549

smaller

d-517

greater

A·I·R ©1960

d-504

not pass through the principal focus

d-536

converge (diverge)
diverge (converge)

d-568

I

d-600

magnified
focal length

d-632

principal axis
object
optical center
object distance

A·I·R ©1960

D-645

In a microscope, if M_o is 15, and M_e is 20, M, the overall magnification, is $\boxed{\#}$.

D-613

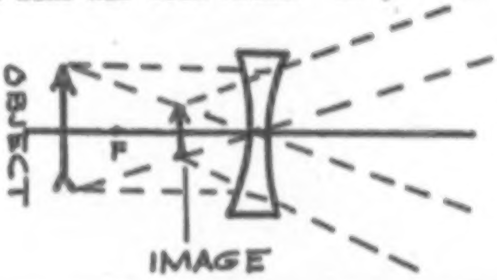
For the formula $\frac{F}{f}$, if we have the ratio $\frac{75}{5}$, we know the focal length of the objective lens is $\boxed{\#}$ inches, and the focal length of the eyepiece is $\boxed{\#}$ inches. The magnifying power of the combination is $\boxed{\#}$.

D-581

The formula for finding d_i when f and d_o are known is $\boxed{\$}$. If f = 3 and and $d_o = 9$, $\frac{1}{d_i} = \boxed{\#}$ and $d_i = \boxed{\#}$.

D-549

In this figure, the image formed by a concave lens has been drawn. As you can see, the image seen through a concave lens is (larger/smaller) $\boxed{}$ than the object.



D-517

For a lens with a fixed focal length, there is only one image distance where the image will be sharp and clear for any particular object distance. If an object is close to a lens (as in Figure 1), the correct image distance will be (greater/less) $\boxed{}$ than if the object were farther away (figure 2).

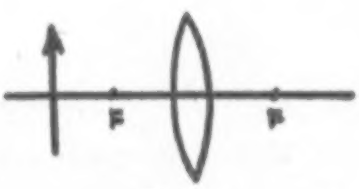


FIG. 1

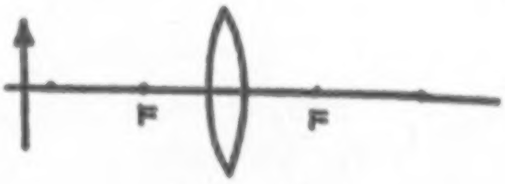


FIG. 2

A·I·R ©1960

D-505

An inexpensive magnifying glass gives us sharp image of objects seen through the center, but the part of the object seen through the edge of the lens seems to have fuzzy edges. The type of defect responsible for this uneven image is caused by the ☐ * of the lens.

D-537

A meniscus lens of the shape shown in Figure 1 is thinner at the center than at the edges. This means that it acts like a ☐ lens and will cause rays of light to ☐. The lens in Figure 2 acts like a ☐ lens and causes light rays to ☐.

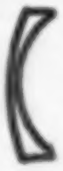


FIG. 1

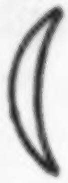
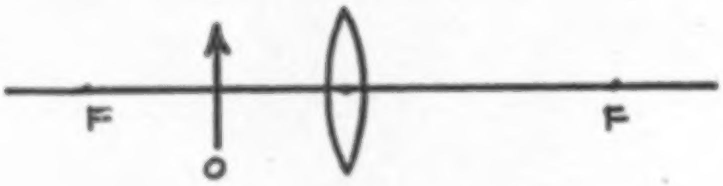


FIG. 2

D-569

Find the image point corresponding to object point O in this figure. Label it I.



D-601

In a telescope, the object lens ☐ the incoming rays of light to form a real ☐ near the eyepiece. The eyepiece, in turn, magnifies this real image, producing the larger virtual ☐ we see.

D-633

M, the magnification produced by any single lens, can be found by using the formula, $M = \frac{d_i}{d_o}$. In words, magnification equals ☐ * divided by ☐ * ☐. We use this formula for any of the magnifying lenses in a microscope, and for the magnifying lenses in a telescope. The formula is not used for the light gathering, or ☐ lenses, of a telescope.

A·I·R ©1960

d-644

magnification of the object lens
magnification of the eyepiece
$M = M_o \times M_e$

d-612

48
magnifying power

d-580

$\frac{1}{d_i}$
(-) 6

d-548

larger
beyond 2F (more than two focal lengths from the lens)

d-516

focal length

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d-505

spherical aberration

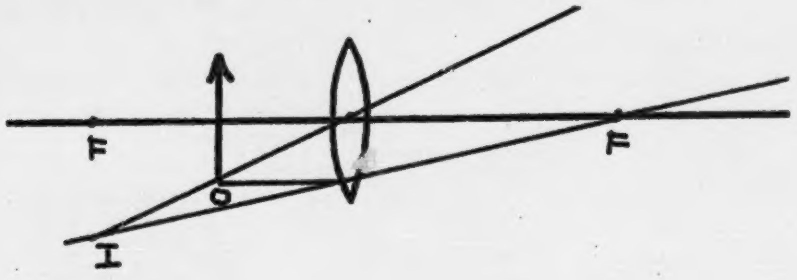
---

d-537

concave
diverge
convex
converge

---

d-569



---

d-601

focuses (or, converges)
image
image

---

d-633

image distance
object distance
object (or, objective)

A·I·R ©1960

D-644

M, the over-all magnification of a two-lens microscope equals M_o, the * , multiplied by M_e, the * . In symbols, the formula is $M = \boxed{\$}$.

D-612

The focal length of an objective lens in a telescope is 48 inches. The eyepiece has a focal length of one inch. In the formula for magnification power of a telescope, $\frac{F}{f} = \frac{48}{1} = \boxed{\#}$, the * of the telescope.

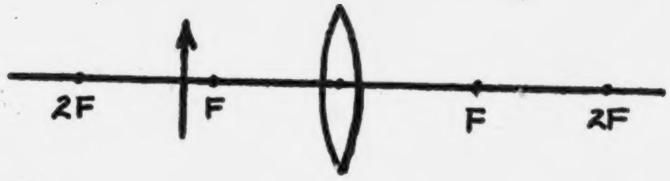
D-580

Use the formula $\frac{1}{f} = \frac{1}{d_o} + \boxed{\$}$ to find d_i when $f = 6$ inches and $d_o = 3$ inches.

In this example, we will have $\frac{1}{6} = \frac{1}{3} + \frac{1}{d_i}$ or $\frac{1}{6} - \frac{1}{3} = \frac{1}{d_i}$. Then, $\frac{1}{d_i} = \frac{1}{6} - \frac{2}{6}$ or $\frac{1}{d_i} = -\frac{1}{6}$. For this problem, $d_i = -\boxed{\#}$.

D-548

Draw in the image for this figure. When an object is between 1F and 2F, its image will be (larger/smaller) than the object. The image will be located * .



D-516

The crystalline lens is more flexible than a camera lens. It can change its shape, becoming thicker or thinner to change its focal length. A camera lens has a fixed focal length. We must replace it with a different lens to change the * in a camera.

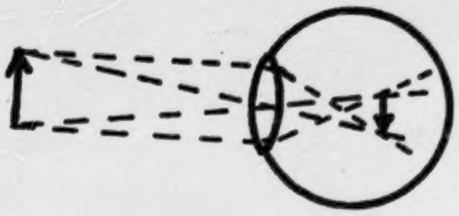
A·I·R ©1960

D-506

In some lenses, a different type of aberration may be found. A chromatic (or color) aberration breaks up white light into the spectrum colors. Rainbow-hued edges on an image are evidence that this lens is limited in the way it refracts white light; it has chromatic ______.

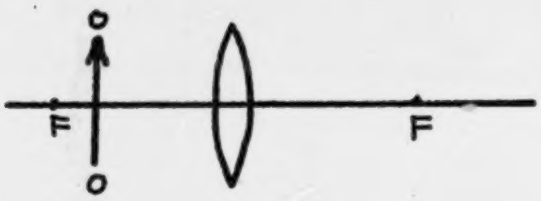
D-538

A myopic, or nearsighted eye defect is drawn below, in which the light rays converge too soon in front of the retina. A corrective lens is needed to spread the rays slightly. For the case below, spectacles should use a concave, or ______ lens to spread the beam slightly.



D-570

Find the image points corresponding to the two object points labeled O in this figure, and draw the image. The image will be virtual, upright, and larger than the object.



D-602

A telescope made of two convex lenses results in the viewer seeing a (real/virtual) ______, (upright/inverted) ______, (magnified/smaller) ______ image.

D-634

We use M as the symbol for magnification, and a small letter following the M to show which microscope lens the formula was used for. M_o (m-sub-oh) stands for the ______ produced by the object lens.

A·I·R ©1960

d-643

over-all magnification

10

100

1000

d-611

$\frac{F}{f}$

d-579

focal length

minus

d-547

smaller

1F and 2F

d-515

crystalline lens

retina

regulate light by providing a larger or smaller opening

A·I·R ©1960

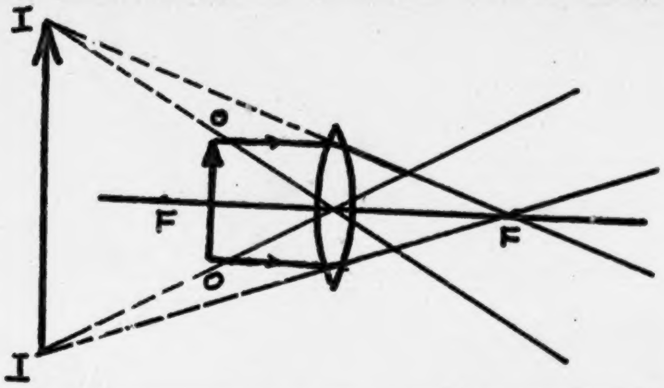
d-506

aberration

d-538

diverging

d-570



d-602

virtual
inverted
magnified

d-634

magnification

A·I·R ©1960

D-643

M, the * , is found by the formula $M = M_o \times M_e$ (where x means "times"). If the magnification of the object lens were 10, and of the eyepiece were 100, the total M would be # multiplied by # or # .

D-611

The magnifying power of a telescope is written in symbols as $\frac{F}{f}$.

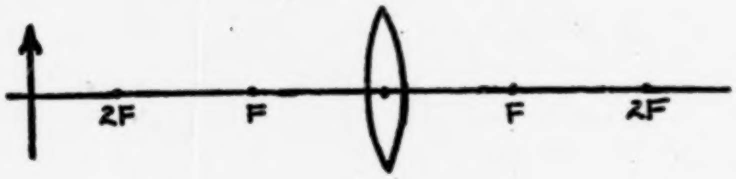
$$\frac{\text{Focal length of the objective lens}}{\text{focal length of eyepiece}} = \frac{\$}{\$} = \text{magnifying power.}$$

D-579

We can use the formula $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$ to find the image distance for a virtual image, but the answer will be a minus number. For instance, if f = 6 inches and d_o = 3 inches, the object distance is less than one * , and d_i will be a ☐ number.

D-547

By locating and drawing the image for this object and lens, you can see that the image of an object placed more than two focal lengths away from the lens will be (larger/smaller) ☐ than the object. The image will be located between * .



D-515

In comparing the human eye and the camera, the lens of a camera corresponds to the * of the eye. The camera film corresponds to the human ☐. The iris of the eye performs the same duty as the diaphragm in a camera which is to ** .

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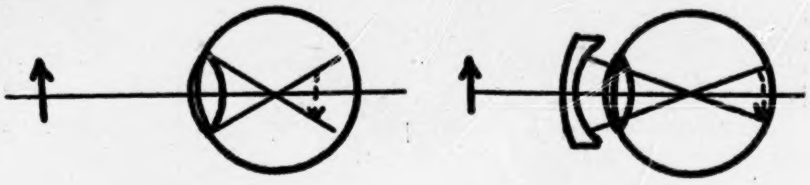
D-507

A rainbow-hued edge on an image is evidence that this lens does not bend all colors of light rays equally. This limitation in the ability of lenses to refract light perfectly is called [*].

D-539

In order to correct for myopia or nearsightedness, which means that light rays converge in front of the retina, we would require a longer focal length. We could use a corrective spectacle lens which caused the original beam to (converge/diverge) [ ] as in Figure 2.



D-571

A virtual image, that is, one which is produced by magnification or by looking at an object through a concave lens, is not formed where rays of light actually [ ]. Instead, the image is located wherever the rays of light which strike our eye seem to be coming from.

D-603

In astronomy, "up" or "down" are not important in viewing the moon or stars. A satisfactory astronomical telescope may therefore be constructed using only two lenses. A magnified, inverted image is characteristic of [ ] telescopes.

D-635

In the formula $M_o = \frac{d_i}{d_o}$, M_o stands for the magnification produced by the [ ] lens.

If we know the image distance and the [*] we can use this formula to find the magnification of the [ ] lens.

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d-642

over-all magnification

d-610

magnifying

d-578

virtual

minus

d-546

1F

2F

1F

1F

2F

d-514

pupils

smaller (or, "contracted")

A·I·R ©1960

㉗⑤

d-507

chromatic aberration

d-539

diverge

d-571

intersect (or, meet)

D-603

astronomical

d-635

object
object distance
object

A·I·R ©1960

D-642

The image which we see at the eyepiece of a microscope has been magnified, then magnified again. This final image is called the over-all magnification of the microscope. We can express this in symbols with the large letter M. M, or the * ______ is the total magnification produced by the lenses in a microscope.

D-610

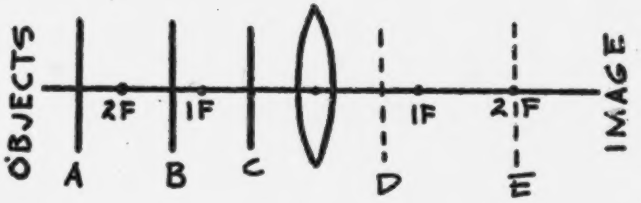
The magnifying power of a telescope is written as $\frac{F}{f}$. "Capital" F means the focal length of the object lens; "small" f is the focal length of the eyepiece. The ratio, or focal length of the object lens divided by the focal length of the eyepiece, is known as the ______ power of the combination.

D-578

If the object is farther from a convex lens than the focal point, we get a real image. If the object is between the focal point and the lens, we get a ______ image. The image distance for a virtual image is always minus. This is indicated by putting a ______ sign before the number.

D-546

Objects and images can be located; that is, their position can be described in terms of focal lengths. Object A, in the figure, is more than 2F from the lens. Object B is between $ ______ and $ ______, while object C is less than $ ______ from the lens. In the same way, image D is less than $ ______ from the lens and image E is exactly at $ ______.



D-514

The iris is the "colored" part of the eye. The dark spot in the center of the iris is the opening, or ______. In bright light, the sensitive retina needs very little light, so our pupils become ______.

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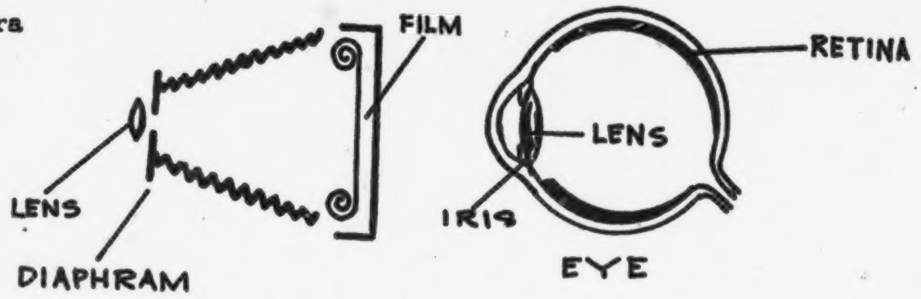
D-508

The human eye is like a camera in many ways. A camera uses a convex glass lens to focus light so that a clear image is formed on the film. The crystalline lens of the eye _____ light on a sensitive receiver of images called the retina.



D-540

Myopia or * _____ is when the image is focused before it reaches the retina. A corrective lens would be used to cause the rays to diverge slightly. We know that a diverging or _____ lens will correct this condition.

D-572

A point on a virtual image is where the light striking our eye * _____. We see virtual images whenever we look at an object through a _____ lens and during magnification; that is, when we view an object through a _____ lens which is located between the lens and the * _____.

D-604

Good lenses are expensive. If we do not need another lens to correct the inverted image, we can use a less expensive instrument. Astronomers get satisfactory results from an instrument producing an inverted image, called an _____ telescope.

D-636

$M_o = \frac{d_i}{d_o}$ means the _____ of the _____ lens is equal to the * _____ divided by the * _____. In this formula for magnification, the image is, of course, virtual. In using this formula, we do not use minus values for d_i.

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d-641

object lens
eyepiece

d-609

light gathering
light gathering power

d-577

focal length

d-545

focal length

d-513

pupil

812

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(279)

d-508

focuses

---

d-540

nearsightedness
concave

---

d-572

seems (appears) to be coming from
concave (or, diverging)
convex (or, converging)
focal point

---

d-604

astronomical

---

d-636

magnification
object
image distance
object distance

A·I·R ©1960

D-641

The over-all magnification produced by a microscope gives us the size the image which reaches our eye. The symbol M stands for over-all magnification, the result of magnification by both the [*] and the [ ] in a microscope.

D-609

The diameter of the object lens of a telescope affects its [*] power and therefore the brightness of the image we see. The greater the diameter of the object lens, the more [*] the lens will have and the brighter the image that we will see.

D-577

Figure 1 shows a real image. The image distance is 12 inches. Figure 2 shows a virtual image. The image distance is - 18 inches (say, minus 18). The image distance is always minus when the object is less than one [*] from the lens.

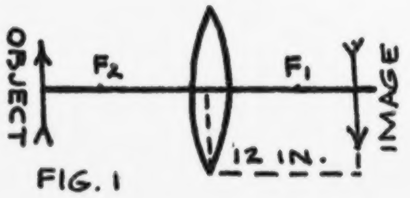

FIG. 1

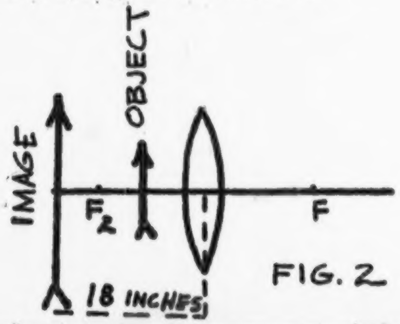

FIG. 2

D-545

You have already learned how images are formed by a convex lens. You found how to locate the image of an object that was placed at 1F, or farther from the lens; that is, at least one [*] away from the lens.

D-513

As the iris opens or closes to regulate the amount of light admitted to the eye, it changes the small opening at its center, called the pupil. The same arrangement in a camera permits larger openings for more light on a dark day. The diaphragm and its opening on a camera therefore, correspond to the iris and the [ ] of the eye.

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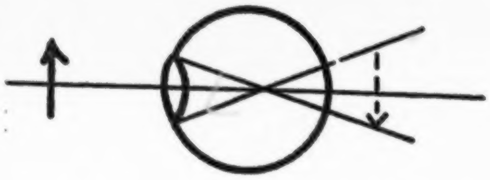
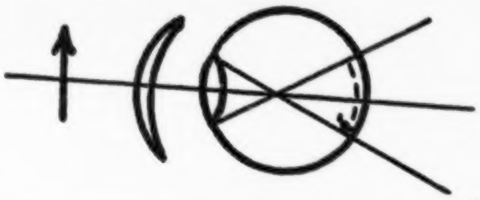
D-509

The crystalline $\boxed{}$ of the human eye focuses light much as a glass lens in a camera. Both refract light rays to form a focused $\boxed{}$ on a light-sensitive area. Both the glass lens of a simple camera and the $\boxed{\ast}$ of the eye are convex shaped.

D-541

Convex lenses cause light to converge; a concave lens diverges or disperses the beam. In a farsighted eye the focus is behind the retina. We need a corrective lens which shortens the focus or converges the beam. We would choose a $\boxed{}$ lens.





D-573

When a lens magnifies an object we are viewing, we know that the object distance is less than $\boxed{}$ focal length.

D-605

It would be inconvenient to use an astronomical telescope to view terrestrial objects such as houses, landscapes, or ships at sea. Since "top" and "bottom" are important in relation to our own position on land, an astronomical telescope, showing objects as $\boxed{}$ or upside down is not satisfactory for $\boxed{}$ use.

D-637

If an object is 4 inches from the lens and virtual image is 8 inches from the lens, the magnification would be found by the formula $M = \boxed{\$}$. In this case, $M = \frac{8}{4}$, or $M =$

$\boxed{\#}$.

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d-640

$(M_o =) \frac{d_i}{d_o}$

$(M_e =) \frac{d_i}{d_o}$

---

d-608

light gathering power (or, the brightness of the image)

---

d-576

seem (appear) to be coming from

---

d-544

image

---

d-512

amount of light entering the eye

A·I·R ©1960

d-509

lens
image
crystalline lens

---

d-541

convex (or, converging)

---

d-573

one

---

d-605

inverted
terrestrial

---

d-637

$\frac{d_i}{d_o}$

2

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D-640

For a compound microscope, the magnification must first be determined for each lens separately. For the object lens, we would use M_o = $ ________ and for the eyepiece the formula would be M_e = $ ________.

D-608

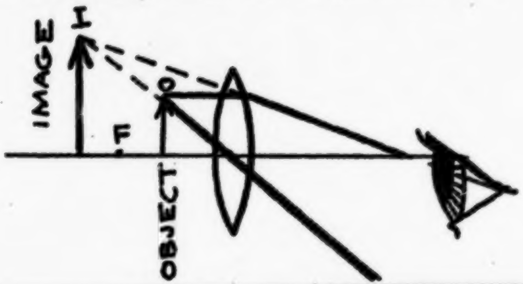
The light gathering power of an objective lens is important, because brighter images are easier to see. In buying binoculars or a telescope, we want a bright image and therefore should check the diameter of the lens before making our purchase. The size of the objective lens determines the ** ________________.

D-576

It is also possible to measure the image distance for a virtual image. A point on a virtual image is where the rays of light * ________________ rather than where the rays of light actually meet or intersect.

D-544

We learned earlier that, by drawing in a secondary axis and a parallel ray from the object point, we could find an image point behind the lens. The point where these lines intersect is called an ________ point.



D-512

The iris of the eye is like the diaphragm of a camera. It regulates the ** ________________.

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D-510

In a camera, the lens causes light to focus on film, which is a light-sensitive material. The retina of the human eye is also a light-sensitive area. Light passes through the [*] of the eye to focus on the [ ].

D-542

The technical name for farsightedness is [ ]. People who have this visual defect see [ ] objects clearly, but are unable to focus sharply on [ ] objects.

D-574

The image produced by a convex lens when the object is located between the focal point and the lens is (inverted/upright) [ ], (larger/smaller) [ ] than the object, and a (real/virtual) [ ] image.

D-606

The inverted image in an astronomical telescope can easily be turned upright by the insertion of an extra lens. A terrestrial telescope, suitable for viewing houses, landscapes or ships has this additional lens, so that any terrestrial object is seen in an [ ] position.

D-638

The symbols $\frac{d_i}{d_o}$ tells us that magnification of any lens is found by dividing the measurements for the [*] by the measurement for the [*]. We can use this formula to find the magnification produced by the eyepiece, or $M_e = \frac{d_i}{d_o}$.

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d-639

object
eyepiece

d-607

bright

d-575

lens (object)
object (lens)
lens to the image (or, image to the lens)

d-543

myopia

d-511

iris

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287

d-510

crystalline lens
retina

d-542

hypermetropia
distant
nearby (or, close)

d-574

upright
larger
virtual

d-606

upright

d-638

image distance
object distance

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D-639

A microscope provides the eye with an enlarged image. This image has been magnified first by the object lens, and then magnified again by the eyepiece. In other words, the image we see is an over-all magnification, which is larger than the image which either the ______ lens or the ______ could produce alone.

D-607

The size of the objective lens of a telescope; that is, the diameter of the piece of glass, does not determine its magnification. The larger across the objective lens is, the more light it brings in, and the brighter the image it will produce. A smaller objective lens brings in less light; the image will be less ______.

D-575

You have already learned that the object distance is the distance from the ______ to the ______, and the image distance for a real image is the distance from the * ______.

D-543

People who are unable to see distant objects clearly have a kind of poor accommodation known as nearsightedness or ______.

D-511

A diaphragm or "stop" regulates the amount of light which enters a camera. This is the part of the camera we adjust for sunny or cloudy days. The iris of the eye narrows or widens to change the amount of light entering the eye. A camera diaphragm or "stop" is therefore much like the ______ of the eye.

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UNIT SIX

REFRACTION AND LENS REVIEW

Steps D-647 through D-809

X (212)

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UNIT ENDS HERE

D-647

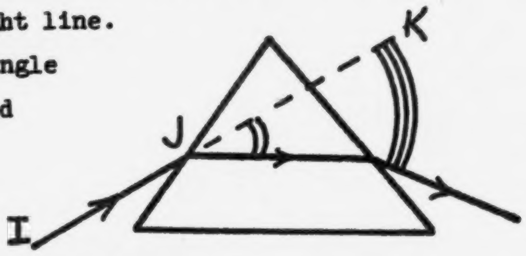
Light is able to travel in many transparent substances. Any substance through which light can travel is called an optical ______.

D-681

When light travels from one medium, such as air or a vacuum, into a second medium, such as glass, that has a higher index of refraction, it will be bent (toward/away from) ______ the normal.

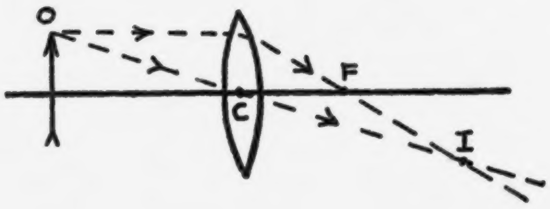
D-715

Dotted line IJK shows the straight path a light ray would take if it were not refracted. As the ray is bent by the prism, it is deviated from this straight line. The angle of deviation shows the total amount of bending. The angle of deviation is the one marked by (two/three) ______ curved lines.



D-749

In the diagram, the intersection of two rays at point I shows the formation of an image point which corresponds to object point $ ______. All rays of light from O which pass through the lens (will/will not) ______ pass through point I.



D-783

For viewing terrestrial objects, such as buildings, landscapes, we would find the astronomical telescope inconvenient because ** ______. To view a building, we would use a ______ telescope, which contains a prism or an added ______.

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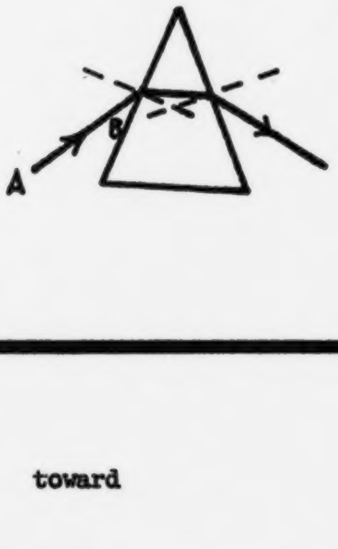
d-782

astronomical telescope

d-748

secondary axis
focal point
bent (or, refracted)

d-714



d-680

toward

A·I·R ©1960

d-647

medium

---

d-681

toward

---

d-715

three

---

d-749

o

will

---

d-783

the image is inverted

terrestrial

lens

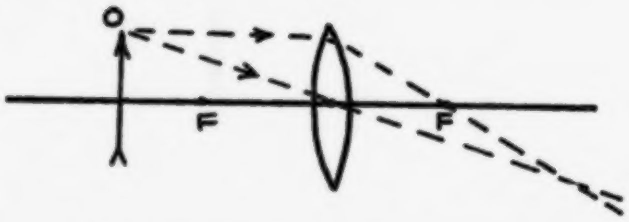
A·I·R ©1960

D-782

We could make a simple optical instrument for viewing astronomical objects such as planets, stars, etc. by placing two convex lenses in a particular way. Using one lens as an object lens, and the other as an eyepiece, we would have an optical instrument known as an ☐ *.

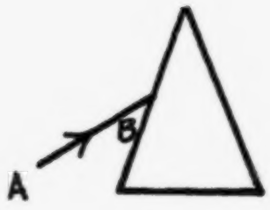
D-748

We can diagram the formation of an image by showing the path of two rays from the object point. One is a ☐ * drawn from point O through the optical center. The second is a parallel ray from O which passes through the ☐ * after it is ☐ by the lens.



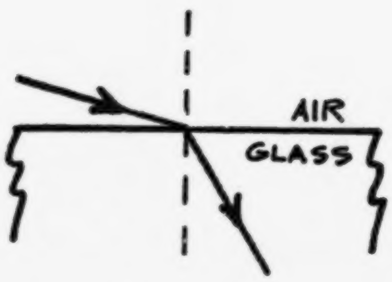
D-714

Line AB represents the path of a ray of light striking a glass prism. Complete the drawing to show the path of light as it passes through and leaves the prism. Use dotted lines to show the normals.



D-680

We use the normal to help describe how refracted light is bent. Light traveling from air to glass, for example, is bent ☐ the normal.



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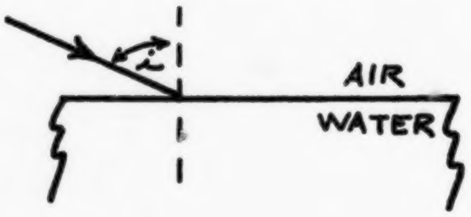
D-648

The plural of the word medium is ______. A vacuum is an example of an * ______ in which light travels; glass, water and diamond are other ______ in which light can travel.

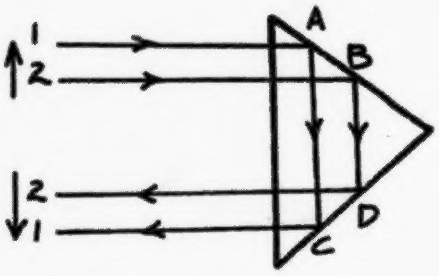
D-682

In the drawing, a ray of light travels from air into water. Water has a (higher/lower) ______ index of refraction than air. The refracted ray, we know, will bend ______ the normal. Draw in the refracted ray.



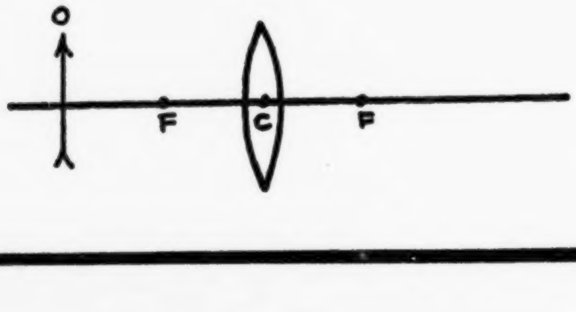
D-716

A prism can invert an image. In the drawing, total reflection takes place at A and B, and again at $ ______ and $ ______. Ray number 1 is on top at first, but on the ______ when it leaves the prism; thus, the image will be ______.



D-750

Draw in a secondary axis and a parallel ray from point O to show the formation of an image point. Label the image point I.



D-784

The magnifying power of a telescope is written $\frac{F}{f}$. Capital F means the focal length of the objective lens; small f is the focal length of the eyepiece. The ratio of $\frac{F}{f}$ is known as the * ______ of the instrument.

A·I·R ©1960

d-781

ocular
magnify

d-747

optical center
optical center

d-713

toward
away from

d-679

bent (or, refracted)
speed (or, velocity)
speed (or, velocity)
vacuum

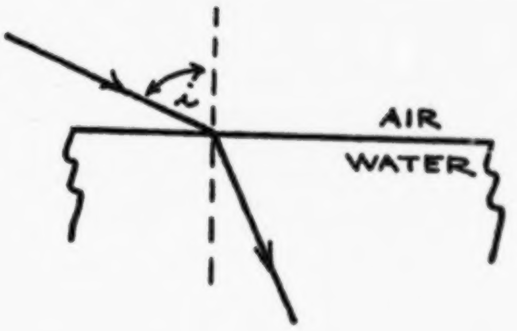
A·I·R ©1960

d-648

media
optical medium (or, transparent medium)
media

d-682

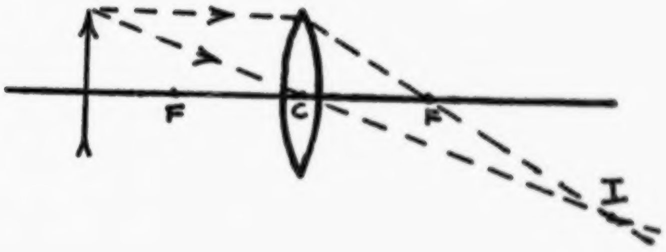
higher
toward



d-716

C (and) D
bottom
inverted

d-750



d-784

magnifying power (or, magnification)

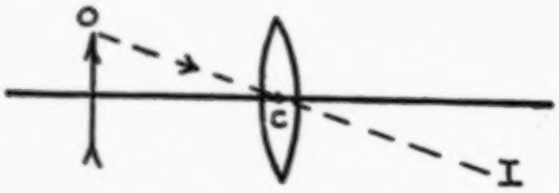
A·I·R ©1960

D-781

In an astronomical telescope, the image behind the first lens is real, inverted, and smaller. The eyepiece or ☐ lens is used to ☐ the size of the object.

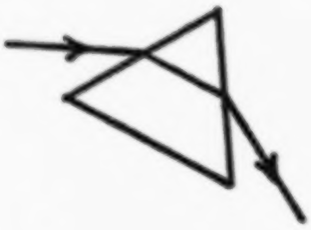
D-747

We can draw a secondary axis from any point on the object. Light rays which travel along a secondary axis from O pass through the ☐ * of the lens to form an image. Rays of light passing through the ☐ * of a lens are not bent.



D-713

Light traveling through a glass object bends twice. It is bent as it goes from air to glass; it bends again as it crosses the boundary back into air. The beam is bent (toward/away from) ☐ the normal as it enters the glass, and then (toward/away from) ☐ the normal as it returns to air.



D-679

We can calculate μ using the formula $\frac{\sin i}{\sin r}$ or the formula $\frac{v_1}{v_2}$. The one known as Snell's Law is based on the amount light is ☐ as it crosses the boundary from one medium to another. The other formula compares the ☐ of light in some medium with the ☐ of light in a ☐.

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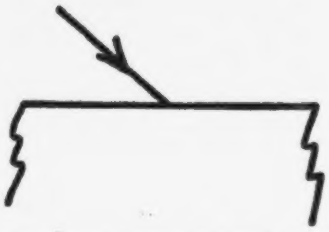
(301)

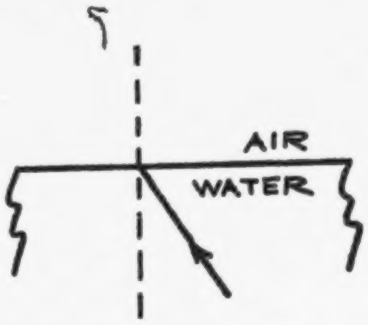
D-649

A ray of light traveling toward the surface of a substance is called an ☐ ray.



D-683

This figure shows a ray of light traveling from water into air. In this case, the light will bend ☐ * ☐ as it enters the air. Draw the refracted ray.



D-717

Figure 1 illustrates a double ☐ lens. The lens in Figure 2 has a ☐ * shape.

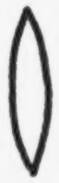


FIG. 1

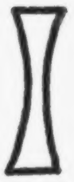
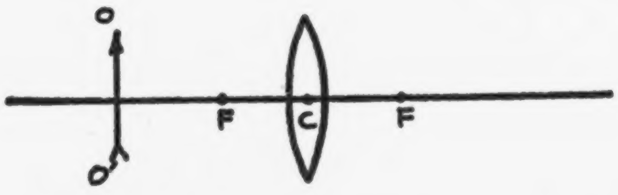


FIG. 2

D-751

Draw in the necessary lines to show the formation of image points corresponding to both O and O'. To complete the drawing, draw in the inverted image between these image points.



D-785

$M = \frac{F}{f}$ is the formula for the ☐ power of a telescope. We must know the ☐ length of the objective lens and the ☐ * of the ☐ to compute M.

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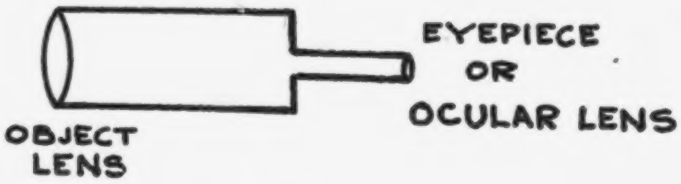
d-780


EYEPIECE
OR
OCULAR LENS
OBJECT
LENS

d-746

principal
focal point
principal
focal point

d-712

prism
parallel
incident

d-678

$(\mu =) \frac{\sin i}{\sin r}$

$(\mu =) \frac{.500}{.318} (=) 1.57$

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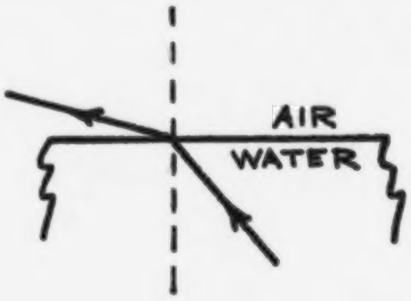
d-649

incident

---

d-683

away from the normal



---

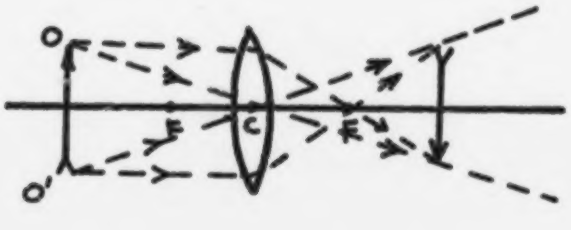
d-717

convex

double concave

---

d-751



---

d-785

magnifying

focal

focal length

eyepiece

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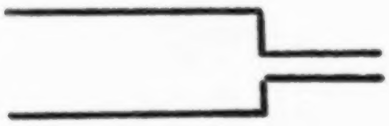
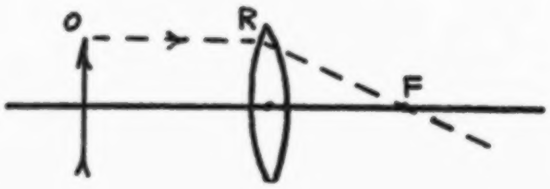
D-780

A basic telescope consists of two lenses, the object lens and the eyepiece. Draw in lenses of the correct shape below, and label each.



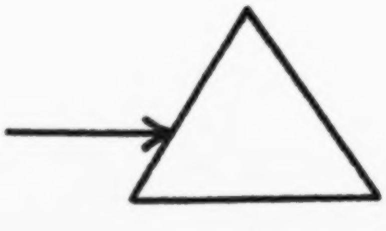
D-746

In image formation diagrams, we speak of a "parallel" ray from the object point. Line OR is drawn parallel to the ☐ axis. When it leaves the lens, it passes through F, the * . All rays of light parallel to the ☐ axis will pass through the * .



D-712

This object, a ☐, does not have parallel sides. We would not expect the light to leave in a path which was ☐ to the path of the incoming or ☐ ray.



D-678

Experimenting with a piece of quartz, we make the sine of the angle of incidence .500 and find the sine of the angle of refraction is .318. In order to find the index of refraction, these figures could be substituted in the Snell's Law formula, μ = $. We would then have μ = # = # as the index of refraction for quartz.

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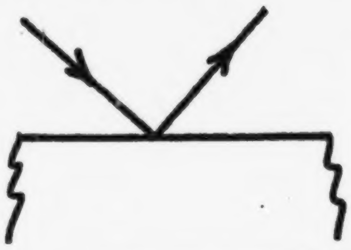
D-650

When an incident ray of light strikes a surface such as polished metal and bounces away, we say the light has been ______.



D-684

Light traveling from a medium which has a low index of refraction (air, for example) to a medium which has a high refractive index (like glass), will bend * ______.

D-718

A plano-convex lens has one ______ and one ______ surface. Draw a plano-convex lens.

D-752

An image point is formed where ** ______ ______.

D-786

A small telescope is built with an object lens of 21 inches; the focal length of the eyepiece is one-half inch (.5). Using the formula $\frac{F}{f}$, the magnifying power of this telescope is found to be # ______.

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d-779

virtual
erect
object

d-745

image
image point

d-711

displacement
parallel

d-677

$\mu = \frac{\sin i}{\sin r}$

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d-650

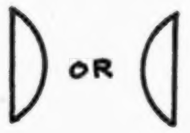
reflected

d-684

toward the normal

d-718

plane (or, straight)
convex (or, curved)



d-752

all the rays of light leaving a given object point which pass through a lens converge or meet or intersect.

d-786

42

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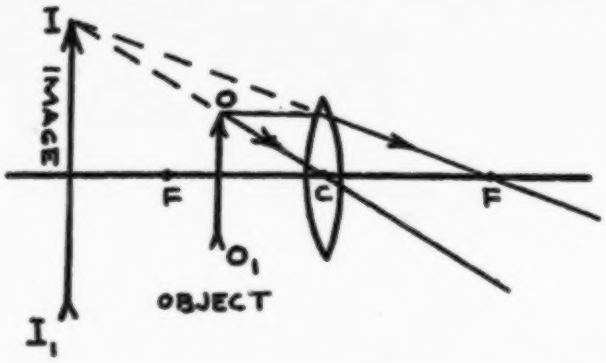
D-779

Magnified images are virtual and erect. In the drawing, the image I-I_1 is a magnified image. It is (real/virtual) ______, (erect/inverted) ______, and larger than the object. Note that this image appears on the same side of the lens as the ______.



D-745

A focused image is a clear reproduction of the object. This is obtained when the lens focuses all the rays from any one object point at one spot, called an ______ point. Each object point has a corresponding * ______.

D-711

Lateral ______ will only occur when light enters and leaves an object which has ______ sides.

D-677

The formula for finding μ by means of Snell's Law is written in symbols as

$ ______.

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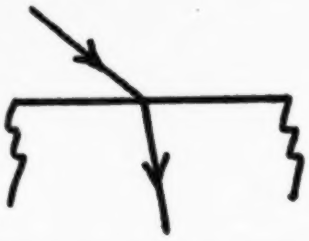
(309)

D-651

When an incident ray strikes a surface and then travels into another medium, we say that ________ has taken place.



D-685

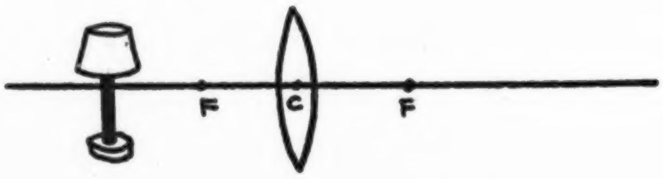
Light rays traveling from a medium which has a high index of refraction to one with a lower μ will bend * ________. Light rays traveling from water to air will bend * ________.

D-719

Another name for a convex lens is a ________ lens, which means that it causes parallel light rays to ** ________.

D-753

Locate and draw the image corresponding to this object.



D-787

Using the symbol "x" to mean the magnifying power of a lens, we could say that a telescope labeled 50x will produce an image which is ** ________ than the object would ordinarily appear at that distance.

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d-778

object

same side of the lens as the object

---

d-744

24

image distance

---

d-710

entered

plane-parallel

lateral

---

d-676

incidence (refraction)

refraction (incidence)

index of refraction

Snell's Law

A·I·R ©1960

(311)

d-651

refraction

d-685

away from the normal

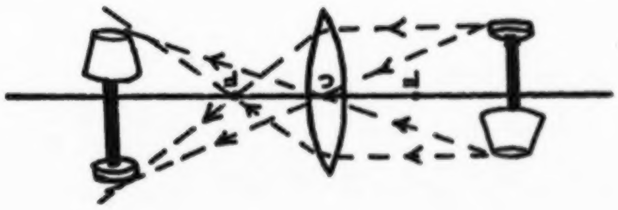
away from the normal

d-719

converging

meet at a point (or, come together, converge)

d-753



d-787

50 times larger

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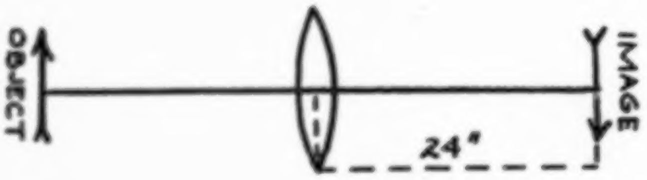
D-778

A real image is formed on the side of the lens opposite the [ ]; a virtual image is formed on the [**].

D-744

In the drawing, the image is located [#] inches from the center of the lens. This distance is called the [*].



D-710

A plane-parallel shape has parallel sides. Light will leave a block which is shaped this way at exactly the same angle at which it [ ]. We would use a [ ] shape to cause the sideways motion of light called [ ] displacement.

D-676

Using the sine of the angle of [ ] and the sine of the angle of [ ] we can find a proportion known as μ , the [*]. This formula is known as [*].

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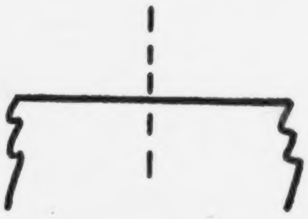
D-652

An imaginary line perpendicular to a surface is called a ______. In this figure, the dotted line represents a ______.

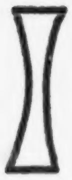


D-686

Light usually bends as it changes speed. The higher the index of refraction of a transparent medium, the (more/less) ______ light will be bent as it enters it from a vacuum, and the (faster/slower) ______ it will travel. Light traveling from air to diamond will be bent (more/less) ______ than light traveling from air to glass.

D-720

This figure illustrates a double ______ lens. It causes light to * ______. For that reason, it is also called a ______ lens.



D-754

The symbol d_o stands for * ______, the distance between ** ______ ______.

D-788

Van Leeuwenhoek was one of the first scientists to work with a simple microscope, which had only ______ lens. Jensen, who is thought to have invented the compound microscope, used more than one magnifying lens to increase the apparent size of the ______.

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d-777

cannot
the rays of light seem to be coming from
magnification
concave (or, diverging)
upright

d-743

image
optical center
principal axis

d-709

parallel

d-675

Snell's Law

A·I·R ©1960

315

d-652

normal
normal

d-686

more
slower
more

d-720

concave
move apart (or, diverge)
diverging

d-754

object distance
the object and the optical center of the lens (measured along the principal axis)

d-788

one
object

A·I·R ©1960

D-777

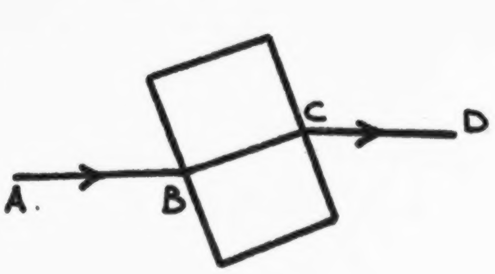
A virtual image (can/cannot) ☐ be projected on a screen. The image is located where ☐ ** . Virtual images are produced by convex lenses during ☐ and by all ☐ lenses. These images are always (upright/inverted) ☐ .

D-743

When we speak of the image distance, we refer to the measurement (in feet, inches, etc.) between the ☐ and the ☐ * of the lens, measured along the ☐ * .

D-709

Using a plane-parallel block we can cause the lateral (or, sideways) displacement of a light ray. Although moved over, line CD will still be ☐ to line AB.



D-675

Light bends as it crosses the boundary from one medium to another. This is represented by the formula $\mu = \frac{\sin i}{\sin r}$, known as ☐ * .

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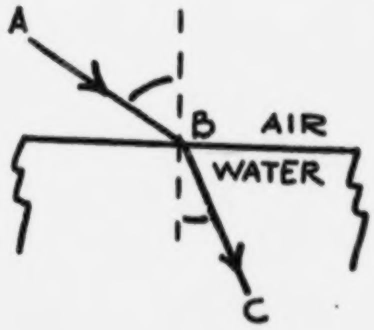
D-653

A normal is always drawn so it is ________ to the surface. When we speak of light bending as it travels from one medium to another, we say light is bent toward or away from the normal. In the drawing, the refracted ray is bent ________ the normal; that is, line BC forms a smaller angle with the normal than the incident ray labeled $ ____.

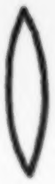


D-687

Although we speak of light bending as it travels from one medium to another, light which strikes perpendicular to the surface of a transparent medium is not ________ as it crosses the boundary. In this case, the incident ray corresponds to the line called the ________.

D-721

Draw several parallel rays of light which are converged by this lens as they pass through it. Use arrows to indicate the direction in which the light is traveling.



D-755

The image distance is measured between the ** ________ ________. In symbols, the image distance is written as $ ____.

D-789

A magnifying glass and a Covington magnifier are both examples of single lens or ________ microscopes. Doublets and triplets, as well as the instruments we would use in a laboratory, are examples of multiple lens or ________ microscopes.

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END OF UNIT

---

d-776

can

rays of light meet or intersect

convex (or, converging)

one focal length from the lens

inverted

---

d-742

36

object distance

---

d-708

parallel

parallel

---

d-674

index of refraction

incidence (refraction)

refraction (incidence)

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d-653

perpendicular
toward
AB

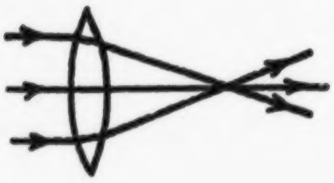
---

d-687

bent
normal

---

d-721



---

d-755

image and the optical center of the lens (measured along the principal axis)
d_i

---

d-789

simple
compound

A·I·R ©1960

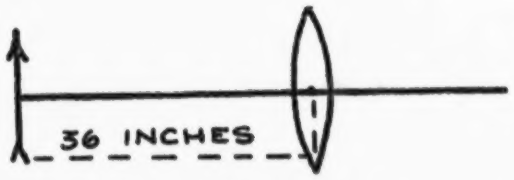
END OF UNIT

D-776

A real image (can/cannot) ______ be projected on a screen. The image is located where ** ______________ . Real images are produced by ______ lenses when the object is greater than ** ______________ . These images are always (upright/inverted) ______ .

D-742

In the drawing, the object is # ______ inches from the center of the lens. This measurement is called the * ______________ .



D-708

We can shape a glass block so that its sides are equal distances from each other. The sides of such a block are ______ to each other. Such a block is described as having a plane- ______ shape.

D-674

We indicate the amount of bending that occurs during refraction by the * ______________ . To compute this value, Snell found we can use the sine of the angle of ______ and the sine of the angle of ______ .

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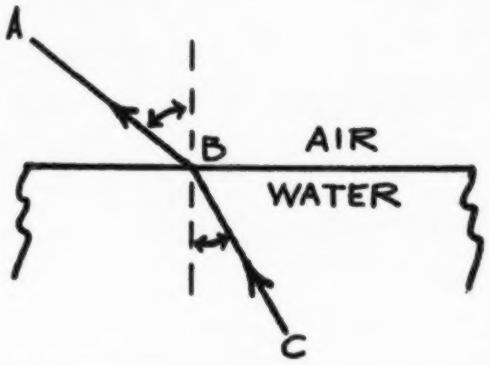
D-654

In the drawing, the incident light ray is line BC. As it crossed the boundary into air, the refracted ray makes a larger angle with the normal; that is, the refracted ray was bent [*] the normal.



D-688

An angle of incidence can be any angle, such as 10° (Figure 1) or 70° (Figure 2). In Figure 3, the incident ray of light coincides with the normal, so the angle of incidence is [ ] degrees.

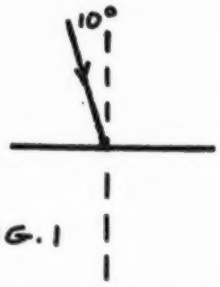


FIG. 1

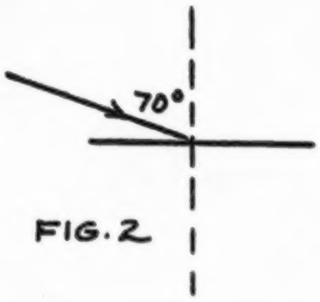


FIG. 2

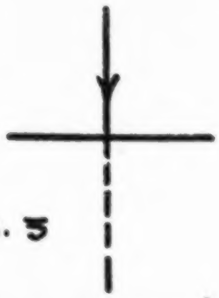
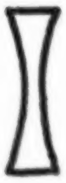


FIG. 3

D-722

Draw several parallel rays of light which are diverged by this lens as they pass through it. Use arrows to indicate the direction the light is traveling.



D-756

The focal length of a lens is the distance measured from the [*] to the [*], measured along the [*]. In symbols, focal length is written as [$].

D-790

An important difference between the microscope and the telescope is that, in a simple microscope, all the lenses are used to [ ] the image, but in a telescope, only the [ ] lens is used this way.

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d-809

the ratio of speed of light in a vacuum divided by the speed of light in another substance (or, the ratio of the sine of the angle of incidence for a substance divided by the sine of the angle of refraction)

d-775

focal point
seems to be coming from
virtual

d-741

AC (or, AF_2C)
CE (or, CF_1E)

d-707

meet (or, intersect, cross)

d-673

$\frac{AB}{AC}$

A·I·R ©1960

㉓

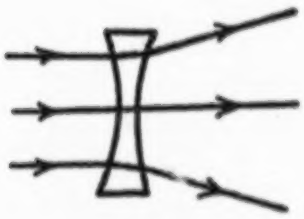
d-654

away from

d-688

zero

d-722



d-756

principal focus (or, focal point)
optical center of the lens
principal axis
f

d-790

magnify
ocular (or, eyepiece)

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D-809

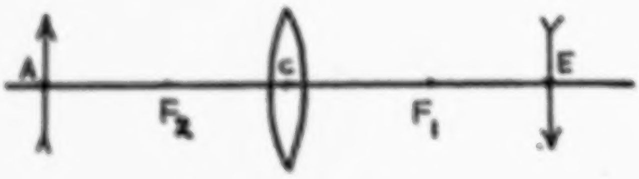
Index of refraction means ** ______ .

D-775

The images produced by diverging lenses and those produced by convex lenses during magnification; that is, when the object is between the lens and the * ______ , cannot be projected on a screen. Such images are located where the light ** ______ . We call these ______ images.

D-741

In the drawing, the object distance is represented by line $ ______ . The image distance is represented by line $ ______ .

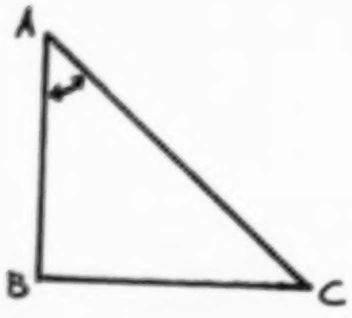


D-707

"Parallel" refers to lines which do not ______ . Draw two lines parallel to each other.

D-673

The sine of an angle is a proportion, the length of the side opposite that angle divided by the length of the hypotenuse in a right triangle. The sine of angle A in this drawing can be written as $\frac{BC}{AC}$. The sine of angle C can be written as $ ______ .



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D-655

The bending or change in direction of a ray of light as it crosses the boundary into another medium is known as ______.

D-689

When light crosses between two media perpendicular to their boundary, the angle of incidence is ______ degrees. The ray of light (will/will not) ______ be bent. Its velocity, however, (will/will not) ______ be changed.

D-723

A meniscus lens has a crescent shape. Eye glass lenses are examples of ______ lenses. Draw a meniscus lens.

D-757

Using the formula $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$, we can solve for d_o, the * ______, or for d_i, the * ______, or for f, the * ______, depending on which of these values are known.

D-791

The formula for the magnification of any single lens is $\frac{d_i}{d_o}$ where d_i means the * ______ of the lens and d_o means the * ______ of the lens.

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d-808

the bending of light rays as they travel from one transparent medium to another

d-774

inverted
screen
real

d-740

object
optical center
principal axis

d-706

Hartl disk
critical

d-672

EF
ED

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327

d-655

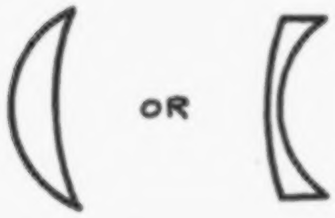
refraction

d-689

zero
will not
will

d-723

meniscus



d-757

object distance
image distance
focal length

d-791

image distance
object distance

A·I·R ©1960

D-808

Refraction is ** ____
______________________________.

D-774

A converging lens often produces an image which is upside down or __________. Such an image cannot be seen by the eye directly, but must be projected on to a __________. These images are formed where rays of light actually intersect. They are called __________ images.

D-740

When we speak of the "object distance," we refer to the measurement (in feet, inches, etc.) between an __________ and the * ______________ of a lens, measured along the * ______________.

D-706

In the laboratory, we use the Hartl disk with its edges marked off in degrees to make direct readings of different angles of incidence or refraction. We can use the * __________ to find the __________ angle, where total reflection occurs for a particular medium.

D-672

In Figure 1, the side opposite angle A is side BC. The hypotenuse is the longest side, AC. In Figure 2, the side opposite angle D is $ ________ and the hypotenuse is line $ ________.

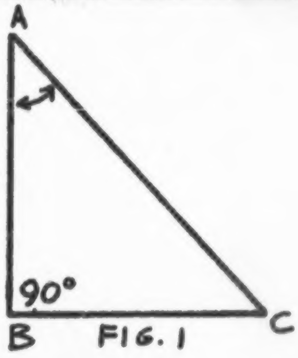


FIG. 1

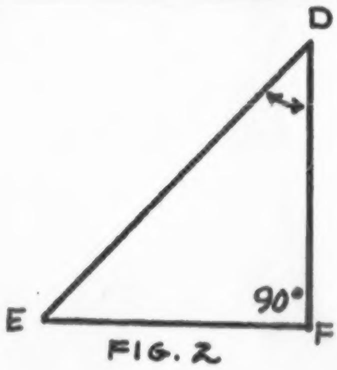


FIG. 2

A·I·R ©1960

D-656

A ray of light which strikes a surface and bounces so that it continues to travel in the same medium is known as a ______ ray. If it crosses the boundary into a second medium, it is known as a ______ ray of light.

D-690

As light crosses the boundary from one medium to another, refraction occurs; that is, its speed or ______ changes and it generally bends, or changes ______.

D-724

Each curved face of a lens may be thought of as being part of the surface of a ______. The more sharply curved the face of a lens, the (larger/smaller) ______ the size of the imaginary ______ of which it is part.

D-758

If the object distance is 30 inches and the image distance is 6 inches, the focal length can be found with the formula $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$. Substituting, $\frac{1}{f} = \frac{1}{30} + \frac{1}{6}$ or, $\frac{1}{f} =$ # ______. Then, f = # ______ or, f = # ______ inches.

D-792

When we refer to the magnification of a lens, we use a small letter as a subscript to indicate which lens is being studied. The formula $M_o = \frac{d_i}{d_o}$ in words, means the ** ______ equals the * ______ divided by the * ______.

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d-807

spherical aberration

d-773

nearsightedness
farsightedness

d-739

focused
focused
focal point

d-705

incidence
critical

d-671

slower
fastest
index of refraction (or, refractive index)

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d-656

reflected
refracted

d-690

velocity
direction

d-724

sphere
smaller
sphere

d-758

$(\frac{1}{f} = \frac{1}{30} + \frac{1}{6} = \frac{1}{30} + \frac{5}{30} =)\ \frac{6}{30}$

$(f =)\ \frac{30}{6}\ (=)\ 5$

d-792

magnification of the object lens
object distance
image distance

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D-807

Most of the parallel light rays traveling through a lens converge at one point. We also know that rays striking near the edges of the lens do not bend the same way, and do not pass through the principal focus. This limitation is called [*].

D-773

An individual who has normal sight receives light focused on his retina as in Figure 1. Figure 2 shows the visual defect known as [ ] or myopia. Figure 3 shows a diagram of the visual defect known as [ ] or hypermetropia.

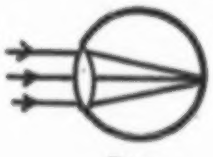

FIG 1

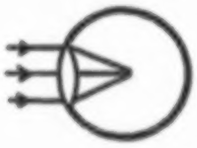

FIG.2

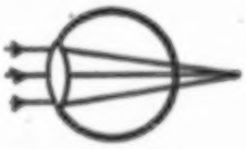

FIG.3

D-739

When converging rays of light form a sharp, clear image, we say it is a [ ] image. Parallel rays of light will converge to a small point; that is, be [ ], at one spot, the [*].

D-705

The angle of incidence which is just large enough to cause total reflection is called the critical angle. Light will be totally reflected when the angle of [ ] is equal to or larger than the [ ] angle.

D-671

Light will travel (faster/slower) [ ] in a medium with an index of refraction of 1.9 than one with an index of refraction of 1.3. Light travels (fastest/slowest) [ ] of all in a vacuum, which has an [*] of 1.0.

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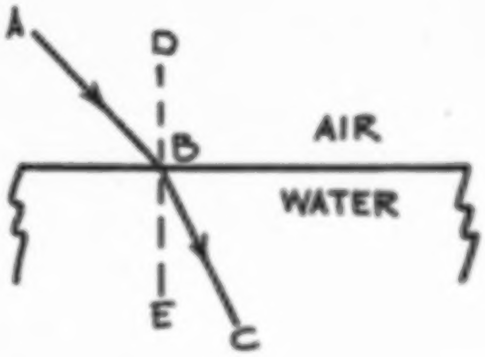
D-657



In the drawing, the incident ray is line $ ______, the refracted ray is line $ ______, and the normal is line $ ______.

D-691

Refraction of light means that two changes are likely to occur as light travels from one transparent medium to another; the light will change in ______ and in ______. The amount of either of these changes can be computed using the proportion known as the * ______.

D-725

A radius of a sphere may be drawn from the center to any point on the surface of the sphere. A radius may also be drawn for the face of a lens. This line would be from the ______ of curvature to any point on the ______ of the lens.

D-759

The formula which shows the relationship between focal length, object distance, and image distance is $ ______

D-793

The separate magnifications of the objective lens and the eyepiece of an optical instrument are combined by multiplying M_o by M_e to give the over-all magnification of a two lens instrument. The over-all magnification of a microscope is (larger/smaller) ______ than the magnification of either lens by itself.

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d-806

boundary
different
does not

d-772

nearsighted
close to the eye
diverging

d-738

are equal
may not

d-704

total reflection
higher

d-670

lower
slower

A·I·R ©1960

d-657

AB
BC
DE(or DBE)

d-691

velocity (or, speed)
direction
index of refraction

d-725

center
surface

d-759

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

d-793

larger

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D-806

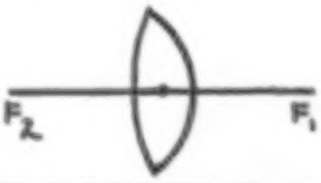
Refraction only occurs at the ______ between two ______ media. The thickness of the materials, therefore, (does/does not) ______ make a difference.

D-772

A myopic or * ______ person focuses best when objects are * ______. He is helped with (converging/diverging) ______ lenses.

D-738

The focal length can be measured on either side of the lens. Regardless of the shape of the lens, the focal lengths on either side of the lens (are equal/are not equal) ______. Each face, however, (may/may not) ______ have the same radius of curvature.



D-704

The ray traveling from water to air in Figure 1 is refracted. In Figure 2, the ray did not escape and we say that * ______ occurred. This can only happen when the first medium has a (higher/lower) ______ μ than the second.

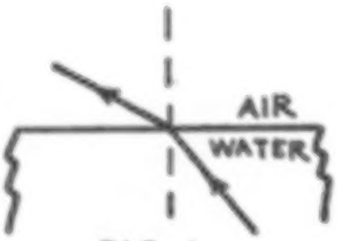


FIG. 1

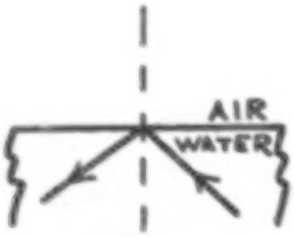


FIG. 2

D-670

Light travels faster in glass than it does in a diamond. The index of refraction for glass is about 1.5, and for diamond it is about 2.4. Light travels faster in media with a (higher/lower) ______ index of refraction. Said another way, the higher the index of refraction for a substance, the (faster/slower) ______ light travels in it.

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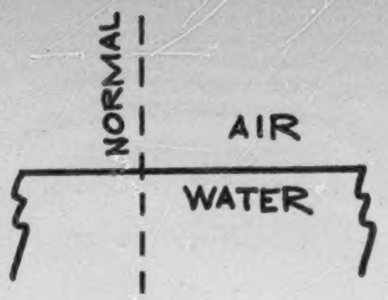
(337)

D-658

Draw and label the path of an incident ray, a reflected ray and a refracted ray.

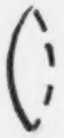


D-692

The change in the velocity of light during refraction is indicated by the refractive index formula, μ = $. We know that, as light goes from a vacuum to ice, its velocity will become (faster/slower) ☐.

D-726

A lens face is shown by a heavy line below. First, extend the curvature to indicate the entire sphere, and then draw in center of curvature and a radius of curvature. Label each.



D-760

If we know the focal length of a lens is 4 inches and the object distance is 8 inches, we can find the image distance. In this case, d_i = # inches.

D-794

When we speak of the "over-all" magnification of a microscope, we mean the magnification of the object lens (added to/multiplied by) * the magnification of the eyepiece.

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11

d-805

convex or converging
focal point
parallel

d-771

farsighted
converging

d-737

principal axis
focal points (or, principal foci)

d-703

total reflection
incidence

d-669

$\mu = \frac{v_1}{v_2}$

125,000

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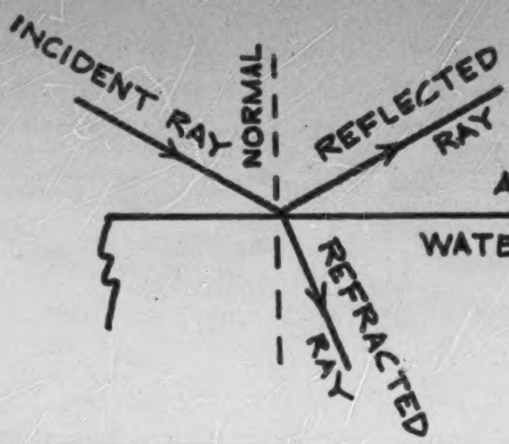
d-658

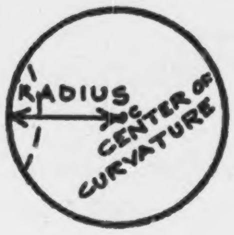

INCIDENT RAY
NORMAL
REFLECTED RAY
AIR
WATER
REFRACTED RAY

d-692

$(\mu =)\ \frac{v_1}{v_2}$

slower

d-726


RADIUS
CENTER OF CURVATURE

d-760

$(\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}\ ,\ \frac{1}{4} = \frac{1}{8} + \frac{1}{d_i}\ ,\ \frac{1}{4} - \frac{1}{8} = \frac{1}{d_i}\ ,\ \frac{1}{8} = \frac{1}{d_i}$; thus, $d_i = \frac{8}{1} =)\ 8$

d-794

multiplied by

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D-805

Parallel light rays are focused by a ______ lens so that they pass through the * ______. If a light source is placed at the principal focus of a lens, the light rays which leave the lens will be ______.

D-771

A hypermetropic person sees images best when objects are located far from his eyes. He is said to be ______. He is helped with eyeglasses made of (converging/diverging) ______ lenses.

D-737

The focal length of a lens is measured along the * ______. It is the distance between the optical center of the lens and either of the * ______.

D-703

Figure 1 shows normal refraction of a light ray. In Figure 2, * ______ has occurred; that is, the angle of ______ is so great that light no longer crosses the boundary between the two media.

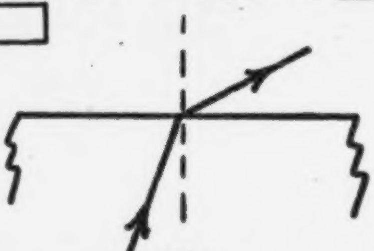

FIG. 1

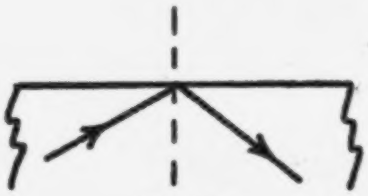

FIG. 2

D-669

By knowing the index of refraction for a substance, we can calculate the speed of light in that medium by using the formula, $ ______. The speed of light in a vacuum is 300,000 kilometers per second. The index of refraction for diamond is about 2.4. The velocity of light in a diamond is therefore about # ______ kilometers per second.

340

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D-659

The angle of incidence is located between the [   ] ray and the normal. Mark the angles of incidence in the drawings with an "i."

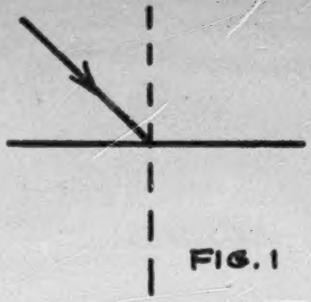


FIG. 1

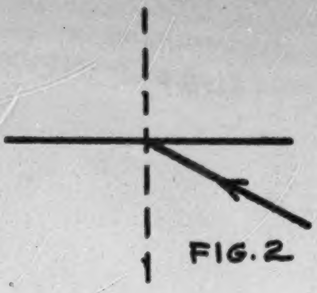


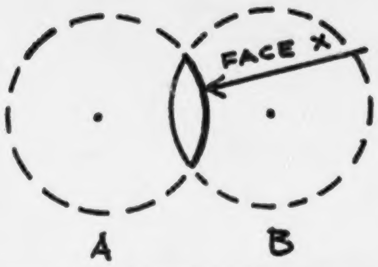
FIG. 2

D-693

The speed of light in a vacuum is 186,000 miles per second. Ice has an index of refraction of 1.33. In ice, the speed of light is (faster/slower) [   ] than in a vacuum, about [#   ] miles per second.

D-727

Draw in a radius of curvature for lens face X. The center of curvature for that face is located in sphere [$].



D-761

All lenses have some aberration, even though it may be very small. There are several kinds of lens limitations, but they are all known generally as [   ].

D-795

The formula $M = M_e \times M_o$ is expressed in words as [**   ]

[   ].

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d-804

clear and distinct
object point
image point

d-770

accommodation

d-736

perpendicular
optical center
secondary axis

d-702

incidence
medium

d-668

1.5

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d-659

incident

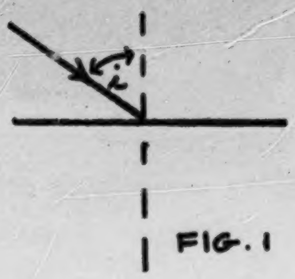


FIG. 1

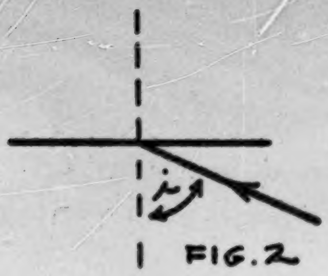
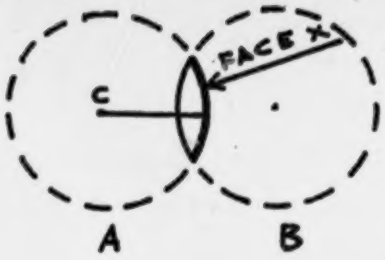


FIG. 2

d-693

slower
139,850

d-727



A

d-761

aberrations

d-795

total magnification equals the magnification of the eyepiece times the magnification of the objective lens

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D-804

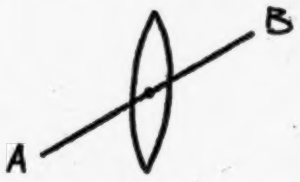
A sharply focused image is one which is * ________. We get a focused image when all the light from any one * ________ meets at exactly one * ________.

D-770

The ciliary muscles control the focus of the crystalline lens in a process called ________.

D-736

A secondary axis is not ________ to the faces of the lens, but it does pass through the * ________ of the lens. In the figure, line AB is a * ________.



D-702

Up to a certain point, as we increase the angle of ________, the angle of refraction also increases. If we increase the angle of incidence too far, however, the light no longer crosses the boundary into the second ________. We call this total reflection.

D-668

The velocity of light in a vacuum is 300,000 kilometers per second. The velocity of light in glass is about 200,000 kilometers per second. Therefore, the index of refraction for glass is about # ________.

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D-660

The angle of refraction is located between the normal and the [ ] ray. Use an "r" in each of the drawings below to indicate the angle of refraction.

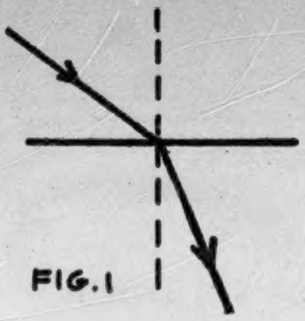


FIG.1

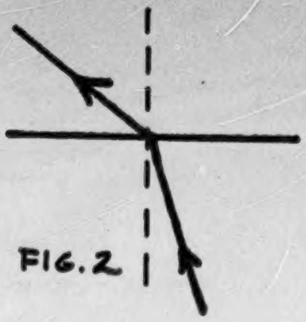


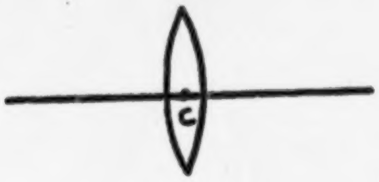
FIG.2

D-694

The change in the direction of light during refraction is indicated by the refractive index formula, μ = [$]. We know that as light goes from air to glass, it will be bent [*]

D-728

A line has been drawn through the optical center of this lens, perpendicular to the faces. This line is known as the [ ] axis of the lens.



D-762

Converging light rays which meet at a common point are said to be focused at that point. The image formed by a camera lens on film must be distinct; that is, the image must be [ ] on the film as perfectly as possible.

D-796

The M_e of a microscope is 20, the M_o is 15. The over-all magnification, whose symbol is [$], is [#].

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d-803

converge
focal point
diverge
focal point

---

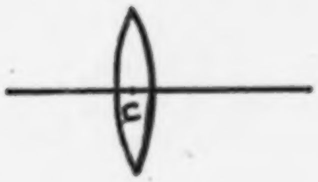
d-769

accommodation
lens

---

d-735

optical center



---

d-701

larger
refraction

---

d-667

the index of refraction equals the speed of light in a vacuum divided by the speed of light in another medium

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d-660

refracted

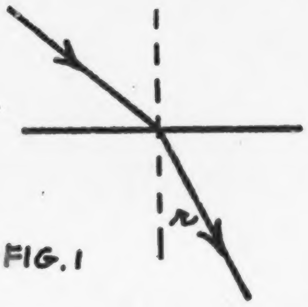

FIG. 1

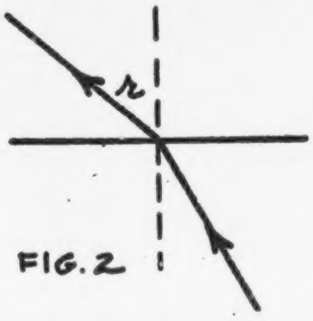

FIG. 2

d-694

$(\mu=)\ \frac{\sin i}{\sin r}$

toward the normal

d-728

principal

d-762

focused

d-796

M

300

A·I·R ©1960

D-803

When parallel rays of light pass through a convex lens, they ______ until they reach the * ______. Then, the rays of light begin to ______. The smallest spot of light will be obtained when the parallel light rays fall on a screen placed at the * ______.

D-769

A camera's lens has one fixed focal length. The process of ______ in the human eye permits us to change focal lengths for vision at different distances. To change the focus in a camera we have to change the distance between the film and the ______.

D-735

The principal axis of a lens is perpendicular to the faces of the lens and passes through the * ______. Draw in a principal axis below.

D-701

We know that a correspondence exists between the angle of incidence and the angle of refraction; that is, as the angle of incidence is made larger, the angle of refraction also becomes ______. By changing the angle of incidence, we also change the angle of ______.

D-667

The formula, $\mu = \frac{v_1}{v_2}$, may be expressed in words as ** ______

______

______

______.

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D-661

Mark "i" and "r" in both drawings to show the angles of incidence and refraction.

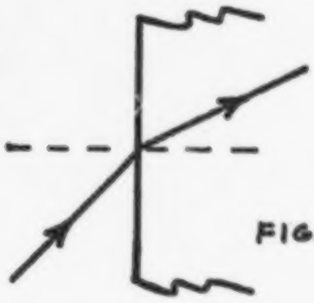


FIG. 1

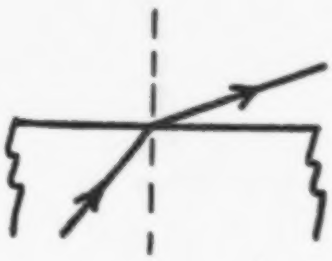


FIG. 2

D-695

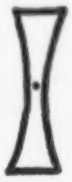
Here is a brief table of sines. If the angle of incidence is 50°, sin i = # . If the angle of refraction is 30°, sin r = # .

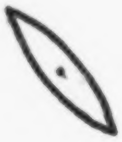
Then, $\mu = \frac{\sin i}{\sin r}$ = # = # .

angle	sine
30°	.500
35°	.574
40°	.643
45°	.707
50°	.766
55°	.819
60°	.866

D-729

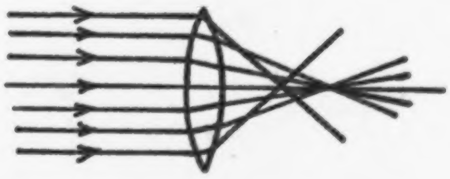
Draw in a principal axis for each of the lenses below. Mark each optical center with a "C."





D-763

In the drawing, light rays do not all meet at one point. The spherical curvature of this lens limits its performance; this type of aberration is known as a * .



D-797

Light rays which travel from one transparent medium to another are bent or as they cross the boundary between the two media.

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d-802

larger

larger

---

d-768

shape (or, focal length)

---

d-734

focal points (or, principal foci)

conjugate

---

d-700

$(\mu = \frac{.866}{.707} =)$ 1.22

---

d-666

index of refraction

$(\mu =) \frac{v_1}{v_2}$

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d-661

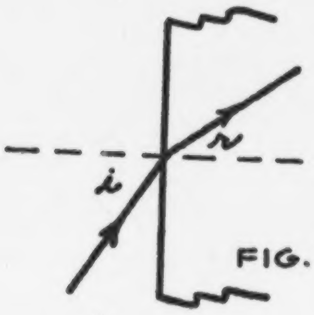


FIG. 1

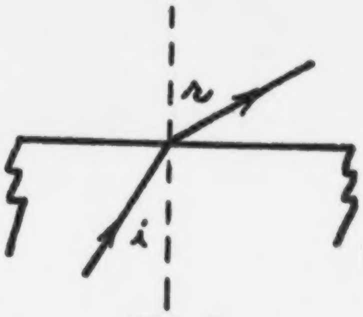


FIG. 2

---

d-695

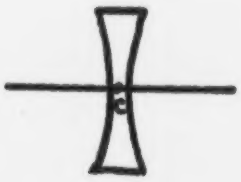
(sin i =) .766

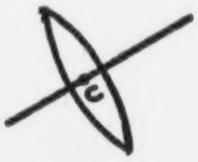
(sin r =) .500

$(\mu =) \frac{.766}{.500} (=) 1.532$

---

d-729





---

d-763

spherical aberration

---

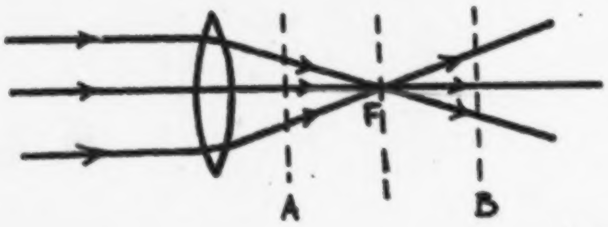
d-797

refracted

A·I·R ©1960

D-802

When parallel rays of light pass through a convex lens, the size of the spot depends on where the screen is placed. The spot will be (larger/smaller) ________ if the screen is at A than at F. It will be (larger/smaller) ________ if the screen is at B than at F.



D-768

The human crystalline lens can accommodate for near and far vision by changing its ________ to suit the distance between the eye and the object.

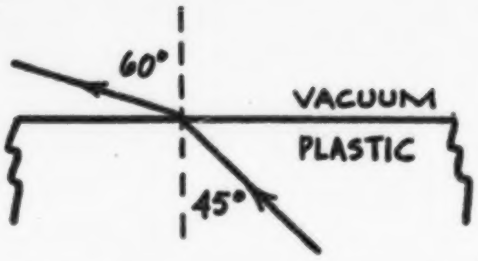
D-734

A lens has a principal focus on each side. "Conjugate foci" refers to the two * ________ which belong to any one lens. The word ________ refers to any two related measures.

D-700

On the basis of the measurements illustrated in this figure, and using this brief table of sines, the index of refraction for the plastic, μ = # ________ .

angle	sine
30°	.500
35°	.574
40°	.643
45°	.707
50°	.766
55°	.819
60°	.866



D-666

Using v_1 as the symbol for light's speed in a vacuum and v_2 for its speed in another medium, we can find μ or the * ________ using the formula

$$\mu = \frac{\$\ \_\_\_\_\_\_}{\$\ \_\_\_\_\_\_}.$$

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D-662

Light travels faster in a ______ than it does in any other medium.

D-696

In computing the index of refraction, a vacuum is always used as the standard. If the formula $\mu = \frac{v_1}{v_2}$ is used, the velocity of light in some substance is compared with the velocity of light in a ______. If the formula $\mu = \frac{\sin i}{\sin r}$ is used, we compare the angle of incidence with the angle of reflection when light goes from a ______ to another medium.

D-730

The focal point or ______ focus of a lens identifies a point on the ______ axis where parallel rays of light ______ or meet after passing through a convex lens.

D-764

The word chromatic refers to "color." A lens which does not focus colors evenly is said to have * ______.

D-798

As light rays travel from one transparent medium to another, we know that changes occur in both velocity and direction. For example, light traveling from material having a low μ, such as ______, to one which has a higher μ, such as ______ will both travel more (rapidly/slowly) ______ and bend (toward/away from) ______ the normal.

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d-801

parallel
principal axis

d-767

light
iris

d-733

two
two
the same

d-699

60
45

d-665

index of refraction
another (transparent) medium

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355

d-662

vacuum

d-696

vacuum
vacuum

d-730

principal
principal
converge (or, focus, meet)

d-764

chromatic aberration

d-798

air (or, vacuum)
glass (or, diamond, ice)
slowly
toward

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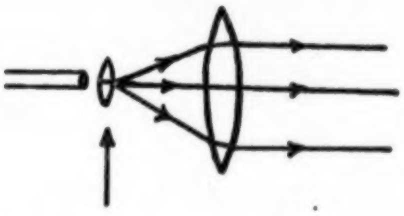
D-801

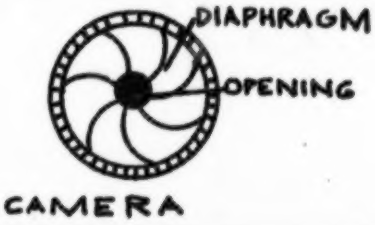
An object placed exactly at the principal focus will not form a focused image on the other side of the lens. The light rays will be parallel as they leave the lens. A searchlight whose bulb (light source) is at the principal focus will send out rays of light which are [ ] to the [*] on the other side of the lens.



D-767

The retina of the eye and the film in a camera both are sensitive to [ ], and receive images focused by their respective lenses. The [ ] of the eye is like the diaphragm of a camera, opening or closing to admit more or less light.

IRIS
PUPIL
EYE

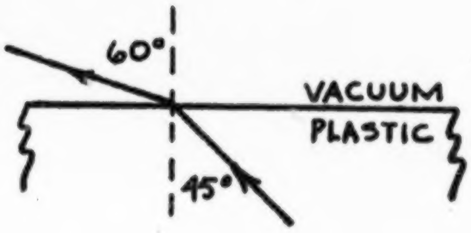


D-733

A lens has two radii of curvature, [ ] centers of curvature and [ ] focal points. While the radius of each face may be different, the focal lengths on either side of the lens are always (the same/different) [ ].

D-699

If we want to find the index of refraction for the plastic illustrated in this figure, we think of the direction of light as being reversed; and use the value, [#] degrees for the angle of incidence and the value, [#] degrees for the angle of reflection.



D-665

The [*] is a proportion which can be found by dividing the velocity of light in a vacuum by the velocity of light in [*].

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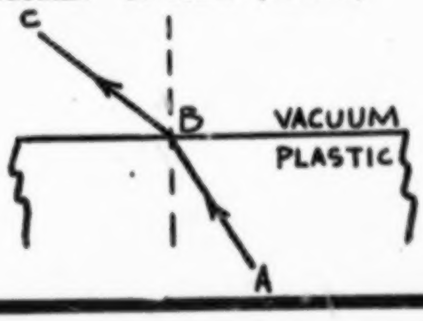
(357)

D-663

The speed of light is different as it travels in a vacuum, in water, or in a diamond. Light travels faster in a ______ than it does in either ______ or a ______.

D-697

In this figure, light goes from transparent plastic to a vacuum. It bends (toward/away from) ______ the normal. We know that light rays are reversible; that is, if the source were at C, the path of the light would be (the same/different) ______.



D-731

Parallel rays of light, passing through a convex lens, meet or converge. They focus at a spot called the * ______.

D-765

A camera has a lens to focus light, a diaphragm which regulates the amount of light entering the camera, and a light-sensitive film to receive the image. The human eye is equipped with a crystalline lens which * ______, an iris which ** ______, and a retina which ** ______.

D-799

Refraction only occurs at the boundary between two different media. If light travels from one piece of a substance directly into another piece of the same substance, the light will neither change in ______ or in ______, regardless of the angle of incidence.

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d-800

reflection (refraction)
refraction (reflection)

---

d-766

lens
crystalline

---

d-732

F_1
principal focus (or, focal point)
F_2

---

d-698

vacuum
reversible

---

d-664

vacuum
bent (or, refracted)

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359

d-663

vacuum
water
diamond

d-697

away from
the same

d-731

focal point (or, principal focus)

d-765

focuses light
regulates amount of light entering the eye
receives the image

d-799

speed (or, velocity) (direction)
direction (speed)

A·I·R ©1960

D-800

Usually, when an incident ray of light strikes a surface, some of the light is bounced from the surface and some of the light enters the second medium; that is, both [ ] and [ ] often occur together.

D-766

The parts of the human eye work much like the parts of a camera. The crystalline lens in the eye is like the [ ] of a camera in that they both focus light on a light-sensitive area. Unlike the glass lens in a camera, however, the shape of the [*] in the eye can be changed.

D-732

The principle of the reversibility of light may be used to show that every lens has two focal points. In Figure 1, the principal focus illustrated is at [$]. The same lens is shown in Figure 2, but the [*] illustrated is at [$], on the other side of the lens.

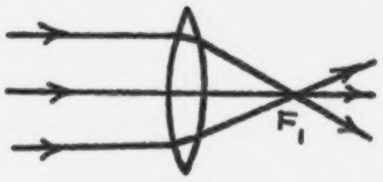

FIG. 1

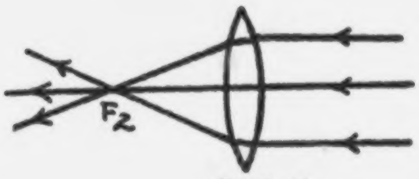

FIG. 2

D-698

To use the formula, $\mu = \frac{\sin i}{\sin r}$, we must have the angles of incidence and reflection when the light is traveling from a [ ] to the substance. If we know the size of the angles when light is traveling from plastic to a vacuum instead, we must use the fact that light rays are [ ], and always call the larger angle the angle of incidence.

D-664

By comparing the speed of light in some medium with the speed of light in a [ ], we can find the index of refraction. The index of refraction tells us how much light will be [ ] as it goes from one medium to another.

A·I·R ©1960

(361)
X

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE

TURN BOOK AROUND AND CONTINUE HERE